File 605/1

[redacted] 25X1

[redacted] 25X1

CONFIDENTIAL

21 September 1959

(IN TRIPLICATE)

~~SECRET~~

[redacted] 25X1

Attention: [redacted] 25X1

Subject: Contract No. 605
Task Order No. 1
Transportable Inflatable Antenna System
Final Engineering Report, Submission of

Enclosure: (A) Final Engineering Report on a High-Gain Transportable Antenna System for the 350 to 10,000 MC Range, thirteen (13) copies

Gentlemen:

Pursuant to the terms and provisions of the subject contract, the contractor submits Enclosure (A), described above, fulfilling the requirement for submission of a final engineering report. Due to the fact the subject contract does not set forth an applicable shipping address, the final report is submitted to your attention with the understanding that the report will be distributed to the applicable parties.

Very truly yours,

1 cy logistics
1 cy cc-4 lib
1 initial file
1 project file (contract)
1 project file (1 Pantemas)
1 to R+D lab

[redacted] 25X1

Contract Administrator
NKG:js

25X1

[redacted]

~~SECRET~~

CONFIDENTIAL

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. ITS TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

25X1

File
Contract 6...

REPORT NO. 1063

CONFIDENTIAL

FINAL ENGINEERING REPORT

ON

A HIGH-GAIN TRANSPORTABLE

ANTENNA SYSTEM

FOR THE 350 TO 10,000 MC RANGE

CONFIDENTIAL

39

Report No. 1063

CONFIDENTIAL

FINAL ENGINEERING REPORT

ON

A HIGH-GAIN TRANSPORTABLE ANTENNA SYSTEM

FOR THE 350 TO 10,000 MC RANGE

1 September 1959

CONFIDENTIAL

ABSTRACT

This is a final report describing the design and development of a receiving-type, high-gain, transportable antenna system for the frequency range of 350 to 10,000 mc. To cover this extremely wide frequency range, two separate antennas were used. One antenna, covering the 350 to 6,000 mc range, consisted of a 6.5-foot inflatable parabolic reflector fed with a log periodic primary feed. The second antenna, covering the 6,000 to 10,000 mc range, consisted of a 2-foot, aluminum, "breakdown type" parabolic reflector fed with an electromagnetic horn.

The contents of an instruction book written for the antenna system which gives a parts list, assembly instructions and electrical performance data is included as a part of this report (appendix I).

A HIGH GAIN TRANSPORTABLE ANTENNA SYSTEM FOR THE 350 TO 10,000 MC RANGE

1. INTRODUCTION

This design and development program was initiated to fulfill a requirement for a receiving-type, high-gain, transportable antenna system to cover the 350 to 10,000 mc range.

In conjunction with the high gain requirement, a beamwidth of two degrees was desirable at 10,000 mc and as near a minimum of 2 degrees as possible over the rest of the frequency range with side lobes at least 10 db down. The antenna system was to be fed with unbalanced 50-ohm transmission line not over 40 feet in length, and the VSWR in the cable was to be no greater than 3:1. Another requirement was that either horizontal or vertical polarization could be readily selected.

As far as physical dimensions were concerned, the assembled antenna system was to fit within a certain confined volume, and in order to facilitate transportability, the construction was to be such that the basic system could be readily assembled, disassembled, and packed in several small boxes. Also, provisions were to be made for mounting the antenna system out-of-doors on a 12-foot, guyed tower which was included as an alternate mounting kit. The system was to be capable of withstanding moderate weather conditions in general and when mounted on the guyed tower be operative in winds up to 60 mph and be capable of surviving in winds up to 70 mph.

The antenna system was to have an azimuth adjustment of 360° with a rough indicating scale to be provided. No elevation adjustment was required.

2. THE ANTENNA SYSTEM

Following is a brief description of the antenna system which was designed and fabricated to meet the above-mentioned requirements.

Two parabolic reflectors with their respective primary feeds are used to cover the required frequency range. For the 350 to 6,000 mc range, a 6.5-foot, inflatable reflector having a f/d ratio of .5 is used. The primary feed for this reflector is a log periodic structure. To cover the 6,000 to 10,000 mc range, a 2-foot aluminum "breakdown type" reflector having a f/d ratio of .4 is utilized. The primary feed for this reflector is a conventional electromagnetic horn. A detailed discussion of the primary feeds will appear in a later section of this report.

The transmission line furnished with each antenna system consists of a total of 80 feet of Prodelin Incorporated Spiroline, 3/8-inch, 50-ohm, polyethylene jacketed coax cable (military number RG-260/U) having an attenuation of 15 db per 100 feet at 10,000 mc. This provides a maximum of 40 feet of transmission line for each antenna. To make the system more versatile, the 40 feet of feed line for each antenna is further broken down into two 8-foot lengths and one 24-foot length.

The 6.5-foot inflatable reflector consists of two plastic-coated, glass fiber reinforced fabric membranes (a reflector membrane treated with a conductive coating to reflect r-f energy and a cover membrane which is transparent to r-f energy) supported by an aluminum ring girder. The edges of the two membranes are clamped securely to the ring girder in such a way as to create an airtight seal between them. The reflector membrane was accurately fabricated so that when the bag is inflated by a small blower to approximately 7 inches of water, it assumes the desired parabolic contour. The contour variation of this reflector was held to less than ±1/8-inch which is approximately 1/16 wavelength at its highest operating frequency of 6,000 mc.

The 2-foot "breakdown" reflector was fabricated by cutting a 2-foot spun-aluminum reflector into four 90° sections. This reflector is 1/8-inch thick and has a contour accuracy of ±1/32 inch (this is less than 1/16 wavelength at 10,000 mc).

When assembled, the 2-foot reflector is attached to the ring girder of the 6.5-foot reflector as shown in figure 2, (appendix I). The apertures of the two reflectors are essentially in the same plane. The large ring girder is, in turn, attached to a hexagonally shaped framework at the rear of the 6.5-foot reflector by six radial struts from the corners of the hexagon. The whole structure is supported by a large vertical tube which is attached to a collapsible quadripod pedestal. When the outdoor mount is used as shown in figure 1 (appendix I), this pedestal clamps to the top of the tower and is used in conjunction with the guy chains to provide twist stability for the antenna system. As shown in figures 1 and 2 (appendix I), the log periodic feed pyramid is held in front of the 6.5-foot reflector by four bakelite feed supports, and the electromagnetic feed horn is held in front of the 2-foot reflector by four metal feed supports.

The basic antenna system when disassembled is packed in the first 7 aluminum boxes, as shown in figure 6 (appendix I). The last two boxes shown in the figure contain the auxiliary outdoor mounting hardware.

2.1 PRIMARY FEED DESIGN

Considered in turn in the following section is the design of the 350 to 6,000 mc log periodic primary feed and the 6,000 to 10,000 mc electromagnetic horn primary feed.

2.1.1 LOG PERIODIC FEED

Prior to the beginning of this project the practicability of a new concept in extremely broadband antennas known as the logarithmically periodic antenna structure had been established. The general pattern and impedance characteristics of various antenna configurations utilizing the log periodic principle, such as linearly polarized omnidirectional, bidirectional and unidirectional structures; circularly polarized bidirectional and unidirectional structures; and unidirectional linearly polarized high-gain arrays had been investigated.[1,2,3,4] From this general investigation and from a later more extensive investigation to optimize the design parameters of the wire, linearly polarized, unidirectional structure, it became apparent that some of these unidirectional structures had the necessary pattern characteristics to make excellent primary feeds for reflector or lens type antennas.

To design a primary feed for a reflector, it is necessary to know the phase center location and behavior with frequency and the amount of aperture blocking caused by the feed, as well as the usual pattern and impedance characteristics.

In the course of this and another similar project, a general investigation was performed to gain a knowledge of the above-mentioned characteristics as a function of the design parameters of trapezoidal-tooth, sheet, log periodic structures. The results of this investigation were given in a previous report. Included in that report are curves of beamwidth, impedance, and phase center location of the sheet, log periodic structure as a function of the design parameters α, ψ, β, and τ. Also given over a 600 to 6,000 mc range are the radiation patterns, gain, beamwidth, and impedance of a 4-foot dish antenna utilizing a log periodic primary feed having design parameters $\alpha = 60, \psi = 45, \beta = 10°$ and $\tau = .707$.

The sheet-type structure was used in the investigations and for the final feed design because a higher degree of accuracy in the modeling techniques could be achieved. All the structures were chemical milled from 1/32-inch thick brass sheet.

The final design of the log periodic primary feed for the 6.5-foot reflector consisted of a basic log periodic structure (design parameters $\alpha = 60°$, $\psi = 45°$, $\tau = .707$ and $\beta = 10°$) lock foamed in an epoxy-impregnated fiberglass, pyramidal shell having base dimensions of 18-1/4 by 12-3/8 inches and a height of 15-3/8 inches. To get a conventional unbalanced 50-ohm input to the feed, the approximately 160-ohm, balanced, average input impedance of the log periodic structure was transformed to an unbalanced 50 ohms by the use of a tapered line balun.

The broken curve in figure 9 (appendix I) shows the free space input VSWR of the log periodic primary feed as a function of frequency over its operating range of 350 to 6,000 mc. As can be seen, the input VSWR is less than 2:1 over more than 50% of the frequency range and has a maximum value of 2.8 to 1 at 4,600 mc.

2.1.2 ELECTROMAGNETIC HORN FEED.

The primary feed for the 2-foot 6,000 to 10,000 mc parabolic reflector consists of an E-plane sectorial electromagnetic horn having aperture dimensions of 1-5/32 by 15/16 inches and an over-all length of 3-3/32 inches. Included as part of the horn assembly is a length of solid dielectric, rigid coax which also serves as one of four feed supports. The feed horn is excited by a voltage probe inserted through one of the broad sides of the short length of waveguide which feeds the horn.

2.2 FINAL ANTENNA SYSTEM PERFORMANCE

Test data taken on the antenna system is summarized and presented in figures 7 through 15 (appendix I). Figure 7 is a plot of E- and H-plane beamwidths as a function of frequency. For the 6.5-foot antenna, the E-plane beamwidth varies from approximately 23 degrees at 350 to 2 degrees at 6,000 mc, while the H-plane beamwidth varies from approximately 21.5 to 2 degrees over the same range. The E- and H-plane beamwidths of the 2-foot dish are approximately equal and vary from 5 degrees at 6,000 mc to 3 degrees at 10,000 mc. Figure 8 compares the measured gain of the system with the theoretical maximum gain of a uniformly illuminated aperture. The gain measurements were made by comparing the gain of the system with standard gain electromagnetic horns. It was not feasible to measure the gain of the system from 350 to 950 mc because no standard gain antennas were available. As can be seen from the figure, the actual gain is less than the theoretical by about 2 db on an average which results in an approximate, practical realizable gain factor of 0.6.[5]

The solid curve of figure 9 is a plot of the input VSWR as a function of frequency for the 6.5-foot antenna. The VSWR is less than 3 to 1 except at three very narrow points where the maximum VSWR is 3.5 to 1. A curve of input VSWR of the 2-foot antenna as a function of frequency is given in figure 10. As can be seen, the VSWR is less than 2 to 1 over its frequency range of 6000 - 10,000 mc. Figures 11 through 13 are representative log plot E- and H-plane patterns of the 6.5-foot antenna. At 350 mc, the side-lobe level is a maximum of approximately -12 db. Figures 14 and 15 are representative log plot E- and H-plane patterns of the 2-foot antenna.

3. CONCLUSION

The design of this high-gain, transportable antenna system satisfies the desired specification requirements with the following exceptions: The beamwidth at 10,000 mc is

Sanitized Copy Approved for Release 2011/09/19 : CIA-RDP78-03424A002000080049-0

approximately 3 degrees instead of 2 degrees and the maximum input VSWR is greater than 3:1 in 3 very narrow frequency bands.

It is felt that the design of this antenna system, which included a general investigation of the log periodic structure as a primary feed, has extended the state-of-the-art in the design of extremely broadband reflector-type antenna systems as well as proved the feasibility of constructing such a system so that it is readily transportable.

4. REFERENCES

1. R. H. DuHamel and D. E. Isbell, "Broadband Logarithmically Periodic Antenna Structures", 1957 IRE National Convention Record, Part I, pp. 119-128.

2. D. E. Isbell, "Non-Planar Logarithmically Periodic Antenna Structures", University of Illinois, Antenna Laboratory TR #30, February 20, 1958, Contract AF 33(616)-3220.

3. R. H. DuHamel and F. R. Ore, "Logarithmically Periodic Antenna Designs", 1958 IRE Convention Record, Part I, pp. 139-151.

4. R. H. DuHamel and D. G. Berry, "Logarithmically Periodic Antenna Arrays", 1958 IRE Wescon Convention Record, Part I, pp. 161-174.

5. S. Silver, "Microwave Antenna Theory and Design", Radiation Laboratory Series #2, McGraw-Hill, 1949, page 415-433.

ADDENDUM

to

**INSTRUCTION BOOK TRANSPORTABLE INFLATABLE ANTENNA SYSTEM
350 to 10,000 MC**

(Part no. 523 0015 00, dated 15 June 1959)

On page 6 of the instruction book described above, add subparagraph 2.1.q.

q. The thumb screws, contained in the tool kit, should be screwed into the external side of the lower ring section hand nuts as needed. This will allow the hand nut handles to be locked in a position where they will not catch on the antenna base when the antenna is rotated.

INSTRUCTION BOOK

TRANSPORTABLE INFLATABLE ANTENNA SYSTEM

350 TO 10,000 MC

523 0015 00
15 JUNE 1959

PRINTED IN THE UNITED STATES OF AMERICA

1.1 GENERAL.

The Transportable Inflatable Antenna System shown in figures 1 and 2 is a lightweight, quickly erected, high gain antenna system in the 350- to 10,000-mc frequency range. It is directional and can be either vertically or horizontally polarized as desired. The antenna system is composed of a 6-1/2-foot inflatable parabolic reflector and feed system covering 350 to 6000 mc, and a two-foot dish reflector and feed horn covering 6000 to 10,000 mc.

The antenna system consists of four main subassemblies:

a. the base assembly, which consists of a portable folding base or a base mounting plate, guy chains, mast, and anchors for outdoor mounting;
b. the inflatable dish assembly, consisting of an inflatable reflector and supporting framework;
c. the logarithmic periodic feed assembly for the inflatable reflector consisting of four support legs, spider, and periodic feed pyramid;
d. and the two-foot dish antenna, which mounts on the frame of the inflatable reflector and covers the higher frequency range of the antenna system.

The electrical characteristics of the antenna system are given in the charts included. A plot of beamwidths in degrees as a function of frequency, for both antennas (figure 7), a plot of gain in db/dipole as a function of frequency for both antennas (figure 8), the input vswr as a function of frequency for the 6-1/2-foot reflector (figure 9), and three charts of radiation patterns for the 6-1/2-foot reflector (figure 11, figure 12, figure 13) are given. The vswr of the two-foot antenna as a function of frequency (figure 9) and two charts of radiation patterns for the two-foot dish (figure 14, figure 15) are also shown.

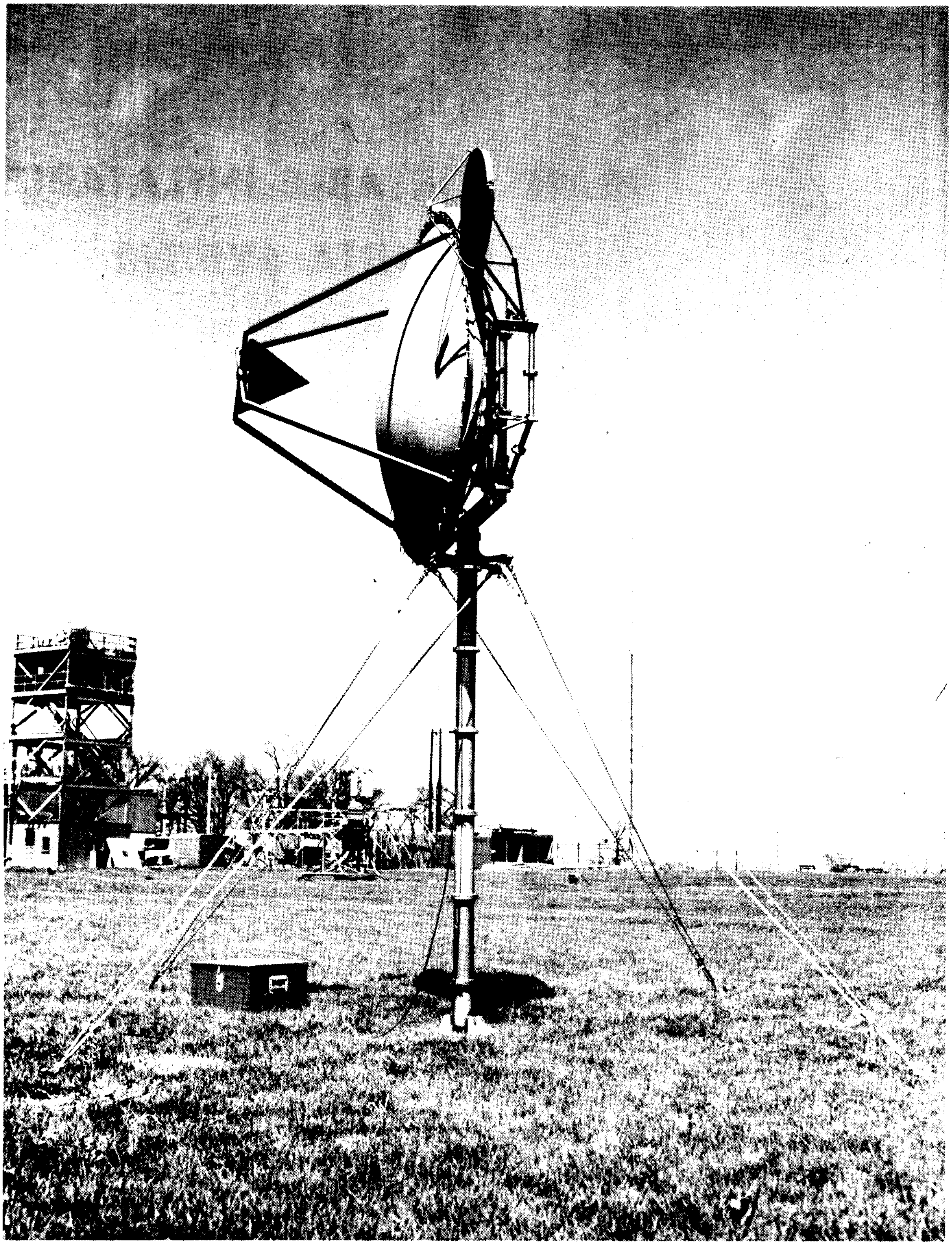


Figure 1. Transportable Inflatable Antenna System on Guyed Mast

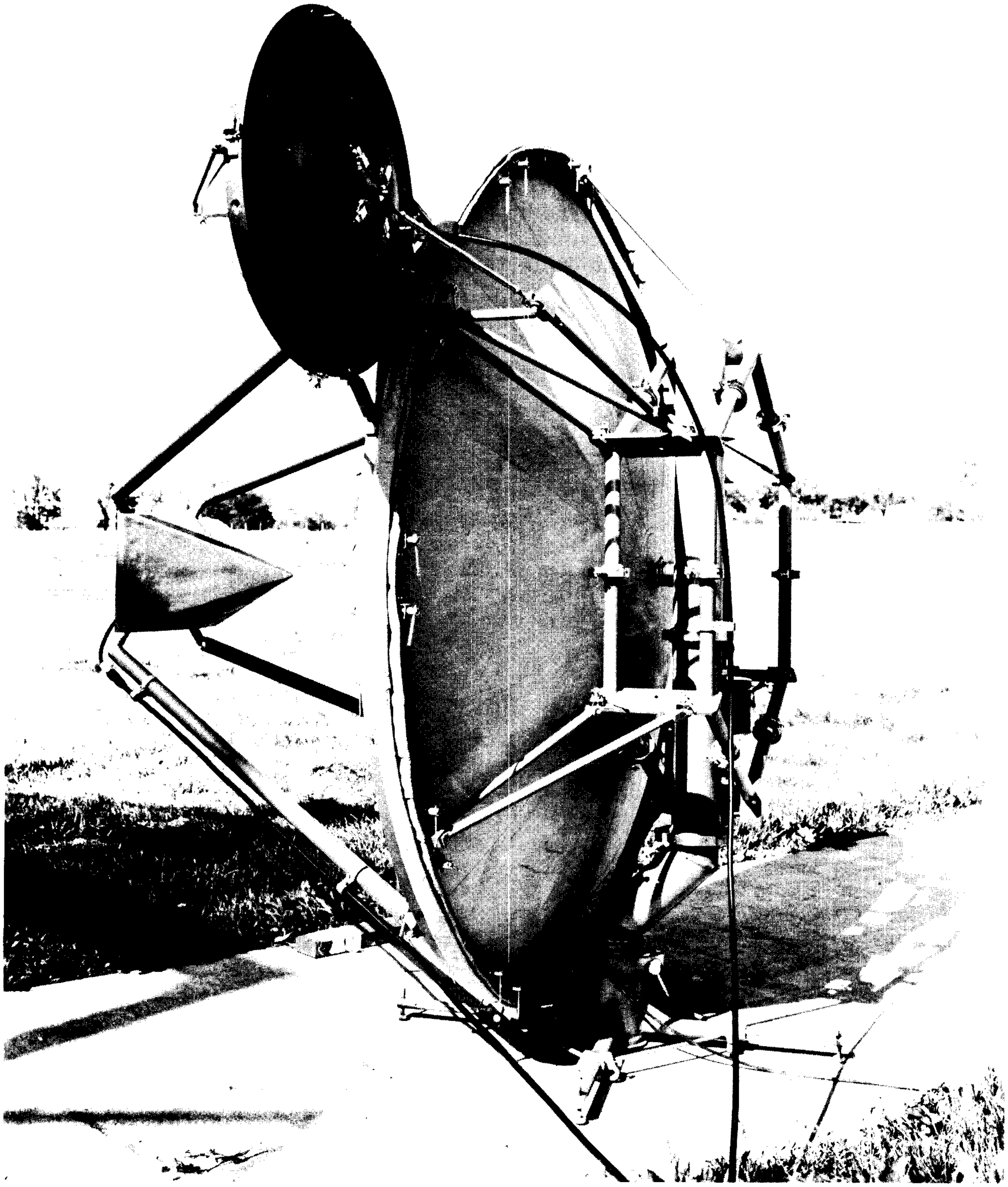


Figure 2. Transportable Inflatable Antenna System on Portable Base

2.1 ASSEMBLY INSTRUCTIONS (Figure 16).

a. Assemble the six frame sections together to form a hexagon-shaped center frame section. The top and bottom sections have special hand nuts that distinguish them from the remaining sections. Place these sections so the threaded portion of the hand nut points to the right when one is looking down at the antenna from the front. Note the position of the ring support holes. Figure 3 shows the frame assembly in detail. The pipe mast is shown in the background of the photo. Fasten together with twelve 2-5/8 in. diameter V-clamps. Tighten wing nuts on V-clamps.

b. Attach six ring supports to the basic frame section. Five supports are identical; one is special and is used to support the small dish antenna that attaches to the side of the main structure. Assembly should be such that the special ring support will be on the upper right when one is facing the antenna. Figure 3 is keyed to show the position of the special ring support arm.

c. Assemble the center support mast with large 6-5/8-in. diameter V-clamps and fasten the mast to the frame assembly. Assemble first the top, middle, and bottom sections of the center mast. The attachment blocks on the top and bottom sections should be parallel with

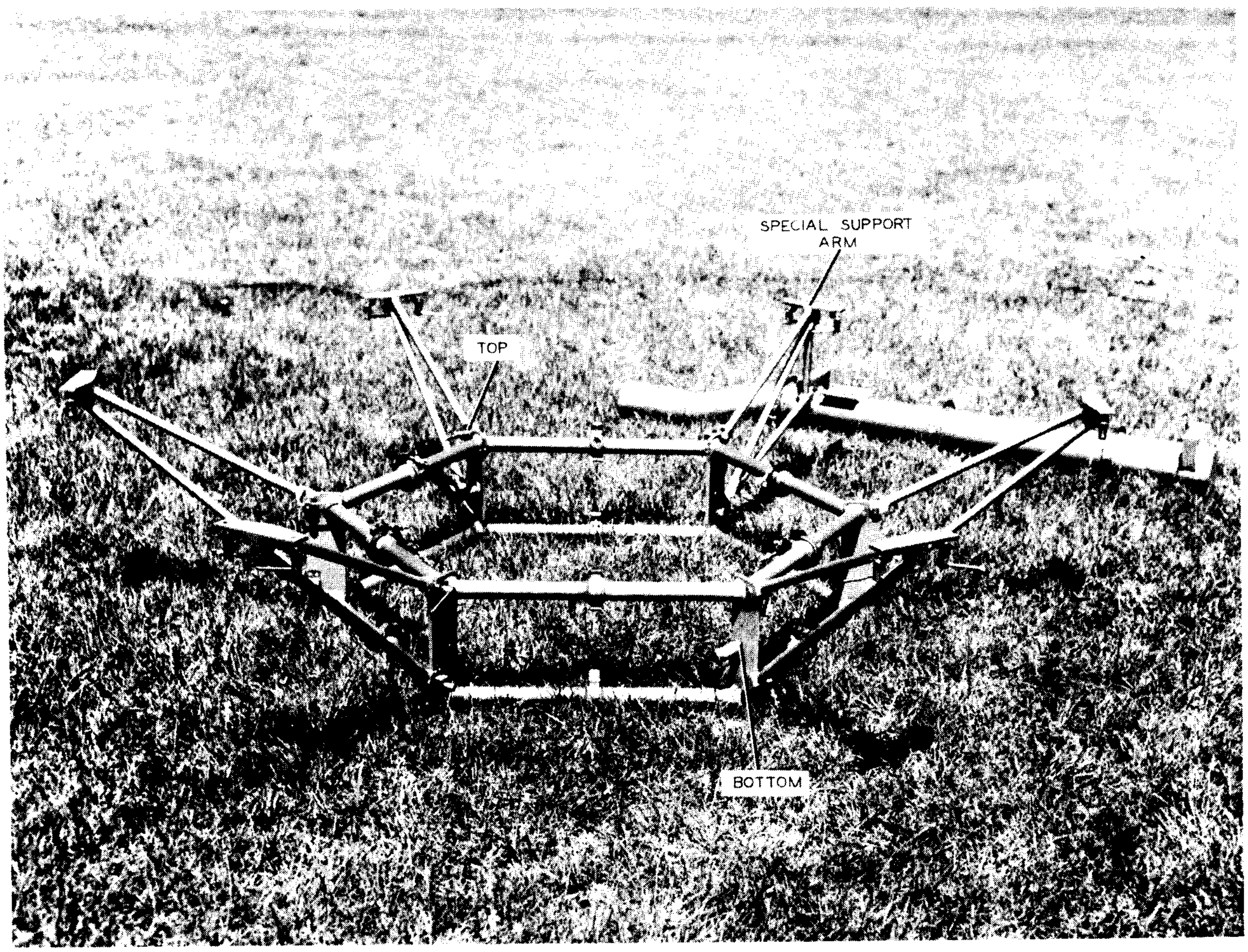


Figure 3. Ring Support Assembly

Sanitized Copy Approved for Release 2011/09/19 : CIA-RDP78-03424A002000080049-0

each other so that they properly fit on the frame assembly. Attach the mast to the right side of the center frame sections. Next attach the lower (crooked) section to the bottom mast section so that there is 2-1/2-in. clearance between the ring support and the edge of the lower (crooked) mast section.

d. Assemble the 12 back ring pieces to the ring supports using hand nuts. Six splice plates join sections not joined at ring supports.

e. Attach the reflecting portion of the inflatable dish, fitting it over the mounting studs on the back ring pieces.

f. Attach the front nonreflecting portion of the inflatable dish over the reflecting portion, fitting it over the mounting studs on the back ring. The inner rope circle of cover and reflector must lie outside all ring sections.

g. Attach the front ring sections to back ring mounting studs. Lay out the front ring sections in position on the antenna so that they overlap the joints on the back ring. The special ring section with the small dish supports should be on the upper right, as is the special ring support. Lay out the four feed support brackets and place at 45 degrees from the vertical and horizontal center lines of the antenna. Assemble the feed support brackets and the adjacent ring sections at the same time. Be sure that the inner rope circle of the cover and reflector lie outside all ring sections. Attach four hand nuts on each front ring section. After all front ring sections and feed support mounting brackets are assembled, lightly hand-tighten the hand nuts around the front ring.

h. Attach the blower assembly to the support mast. The blower assembly slips onto the special mount on the side of the support mast. Clamp the blower hose to the center of the inflatable reflector. Wire the blower as shown in figure 4 for 115-v a-c or 230-v a-c as desired. A 12-v d-c converter and converter cable is furnished for use where 115-v a-c is not readily available. Inflate the antenna with all hand nuts lightly hand tightened. Jar the ring sections so that the air pressure in the antenna will pull the ring into its proper shape. Then tighten all hand nuts, again making sure the inner rope circle of the inner and outer covers are outside the ring sections. Carefully check the seal to see that no air leaks exist. Air pressure in the inflatable reflector should be maintained at seven inches of water.

i. Attach pedestal (for indoor use) to the supporting mast, expand legs, and tighten. The hand nut clamping the pedestal to the supporting mast may be loosened to rotate the antenna. Azimuth is indicated on the azimuth ring on the supporting mast.

j. Assemble the feed support legs to the mounting brackets on the front ring of the antenna.

l. Attach the pyramid support cross (spider) to the four feed support legs.

m. Attach the logarithmic periodic feed pyramid. The feed pyramid can be turned for either vertical or horizontal polarization as indicated by the instructions stenciled on the pyramid itself.

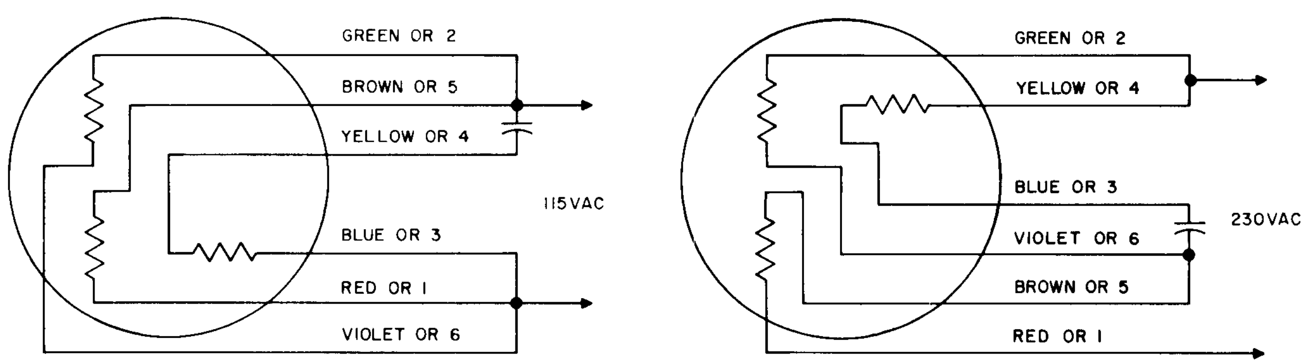


Figure 4. Blower Wiring for 115-V A-C or 230-V A-C

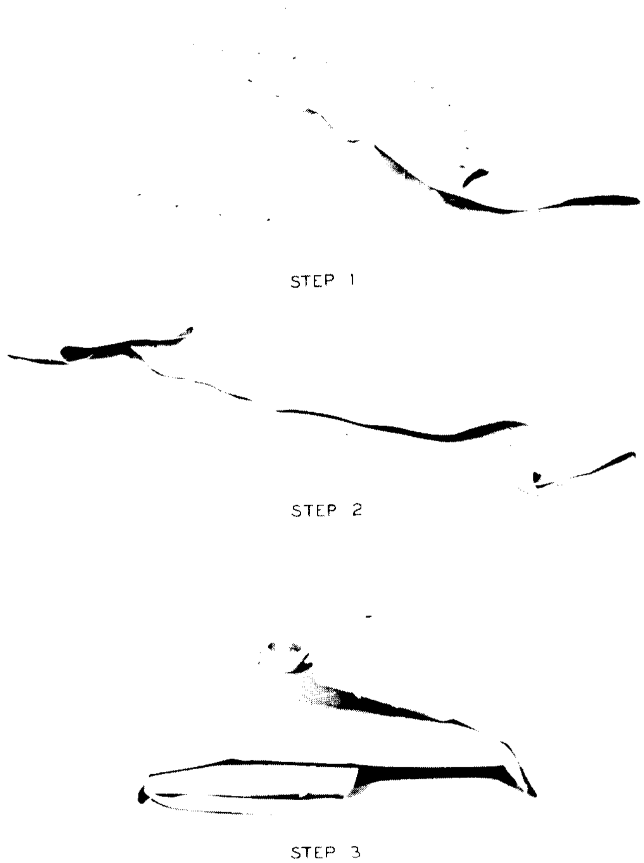


Figure 5. Folding of Inflatable Reflector and Cover

CAUTION

The Fiberglas case of the feed pyramid is fragile; handle with care.

n. Assemble the small dish antenna, clamping the four dish sections together as indicated in the assembly drawing (figure 16). Attach the feed horn assembly and fasten the small dish to the special support mounting brackets on the side of the large antenna. Mount the small dish so that the feed line attachment is at the bottom or left of the small antenna. Attach the semiflexible feed line to the small dish and clamp the feed line to the vertical portion of the hexagon frame with one clamp. Polarization of the small dish is changed by turning the entire antenna 90 degrees as indicated on the feed horn.

CAUTION

Do not kink or sharply bend the semiflexible coaxial feed line. Be extremely careful in shaping this line to avoid damage. Minimum bend radius is six inches.

o. Attach the small coaxial line jumper to the feed pyramid with the right-angle fitting. The other end of the jumper attaches to a length of semiflexible coaxial feed line which clamps to one of the lower feed support legs with two clamps.

p. The antenna may be mounted outdoors with the special plate furnished. Guy chains and anchors are furnished along with a maul for driving the anchors. The guys should be staked nine feet from the base of the antenna regardless of mast height.

3.1 MAINTENANCE AND PACKING.

The complete antenna system is packed in transportable metal boxes. Figure 6 shows the items packed in each box and a suggested manner of arranging the items. Each box contains the following items:

NUMBER	BOX	MFR'S SKETCH NO.
	Box 1	
1	Logarithmic periodic feed pyramid	4020 D 351

NUMBER	BOX	MFR'S SKETCH NO.
	Box 2	
3	V-band clamp assemblies 6-5/8 in. dia.	4020 A 88
1	Top mast section	4020 C 126
1	Center mast section	4020 B 128
1	Bottom mast section	4020 C 143
1	Lower mast section	4020 C 149
1	Base assembly	4020 D 180
	Box 3	
12	V-band clamp assemblies 2-5/8 in. dia.	044 1273 12
4	Frame section assembly, no. 1	4020 C 171
1	Frame section assembly, no. 2	4020 C 172
1	Frame section assembly, no. 3	4020 C 173
	Box 4	
1	Spider assembly	4020 A 96
5	Support rings	4020 D 167
1	Special ring support	4020 D 166
1	2 ft. parabolic reflector, 4 sections	4020 D 342
1	Partition board	4020 B 85
1	Inflatable cover	4020 C 119
	Box 5	
12	Ring section assemblies, back	4020 B 153
11	Front ring section assemblies	4020 C 169
1	Special ring section assembly	4020 C 170
6	Splice plate assemblies	4020 B 214
4	Feed leg bracket assemblies	4020 B 380
	Box 6	
1	Coaxial clamp assembly - No. 3	4020 A 89
2	Coaxial clamp assembly - No. 2	4020 A 90
1	Spool assembly for coaxial line	4020 A 92
1	Coaxial line jumper assembly	4020 A 93
2	Cable assembly - long	4020 A 94
4	Cable assembly - short	4020 A 95
1	Tool kit	4020 A 97
	Box 7	
1	Reflector	4020 C 118
1	Horn leg ass'y - No. 2	4020 B 343
1	Horn leg ass'y - No. 3	4020 B 344
1	Horn leg ass'y - No. 4	4020 B 345
1	Blower cable	4020 A 354
1	Blower motor	4020 D 357

NUMBER	BOX	MFR'S SKETCH NO.
	Box 7 (Cont)	
12	Spider support legs	4020 C 364
1	Small horn ass'y	4020 C 383
1	Converter-vibrator	044 0011 30
1	Converter cable ass'y	4020 A 86
1	Partition board	4020 B 85
1	Dish support	4020 C 196
	Box 8	
6	V-band clamp assy 6-5/8 in. dia.	4020 A 88
2	Coaxial clamp assy - No. 1	4020 A 91
5	Center mast sections	4020 B 128
4	Stake--base	4020 B 155
1	Tower base assy.	4020 A 359
	Box 9	
4	Anchors	4020 C 228
4	Chain	4020 A 358
1	Maul	4020 B 87

Special care should be exercised when folding the inflatable reflector and cover of the antenna. These items should be folded as indicated in figure 5.

A protective coating of Hypalon should be applied annually to the outer surfaces of the cover and reflector fabrics if used outdoors.

3.1.1 BLOWER. The blower contains sealed bearings and does not require lubrication.

CAUTION

Irreparable damage to the cover and reflector fabrics on an erected antenna can result if the fabrics remain uninflated and unprotected from the wind. If the antenna must be left uninflated for extended periods of time, shield the fabric from the major force of the wind. This can be done by tying a canvas cover over the reflector.

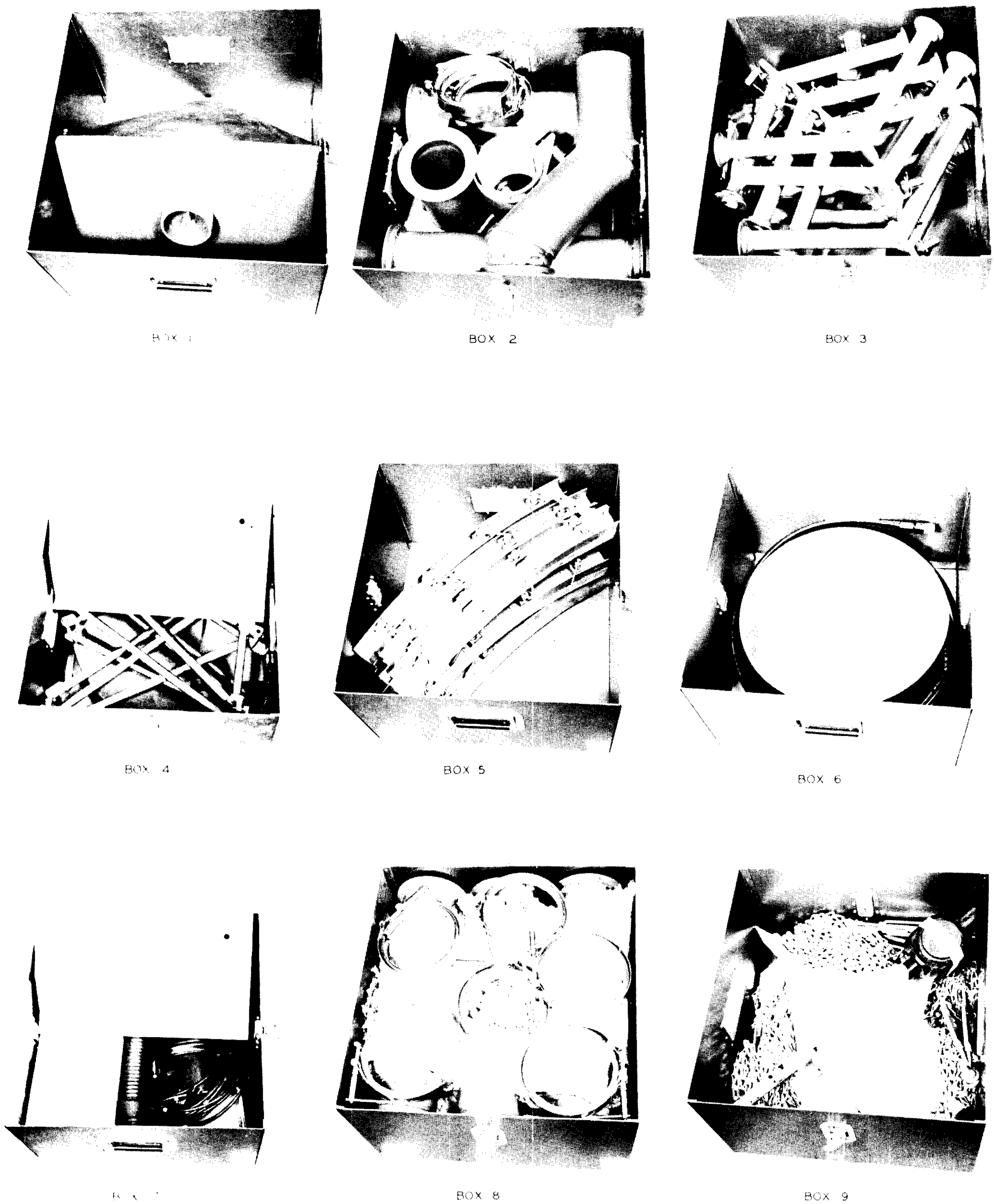


Figure 6. Antenna System Packed in Transportable Metal Boxes

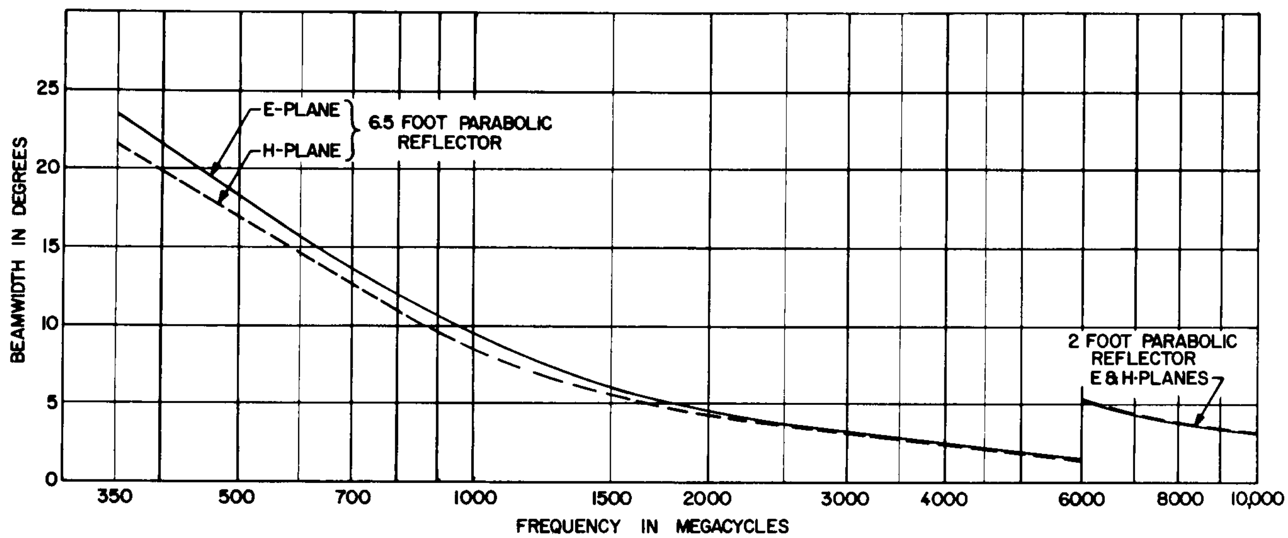


Figure 7. Beamwidth in Degrees as a Function of Frequency

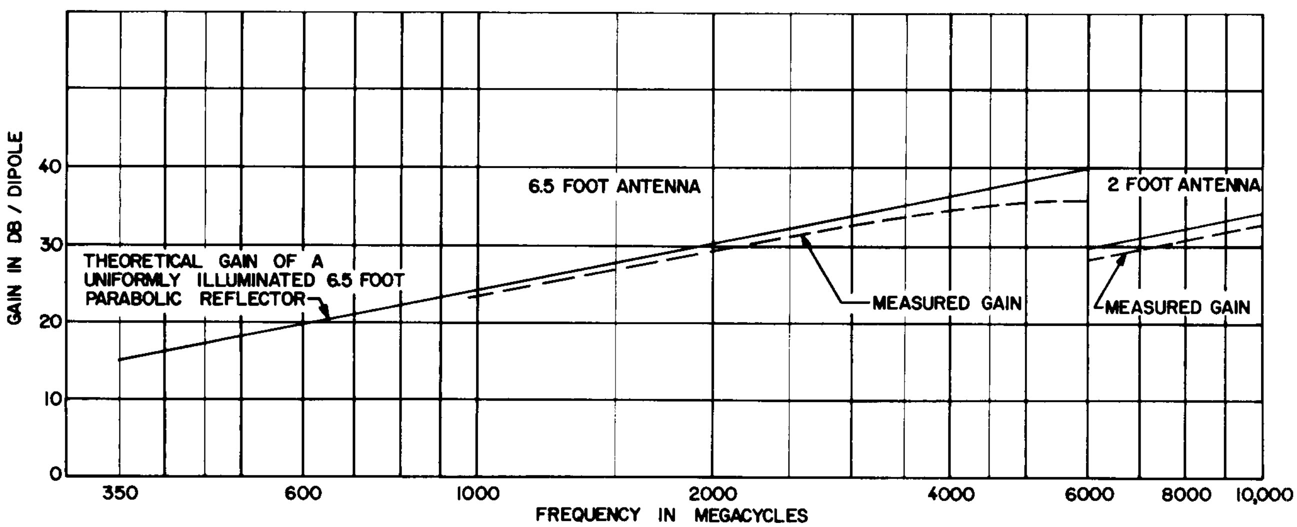


Figure 8. Gain in Db over a Dipole as a Function of Frequency

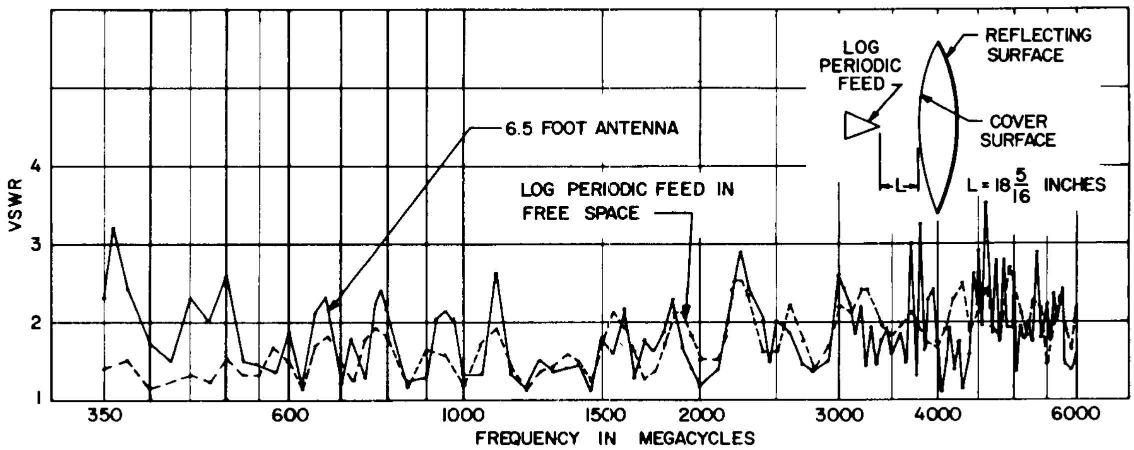


Figure 9. Input VSWR as a Function of Frequency,
6-1/2 Ft. Antenna

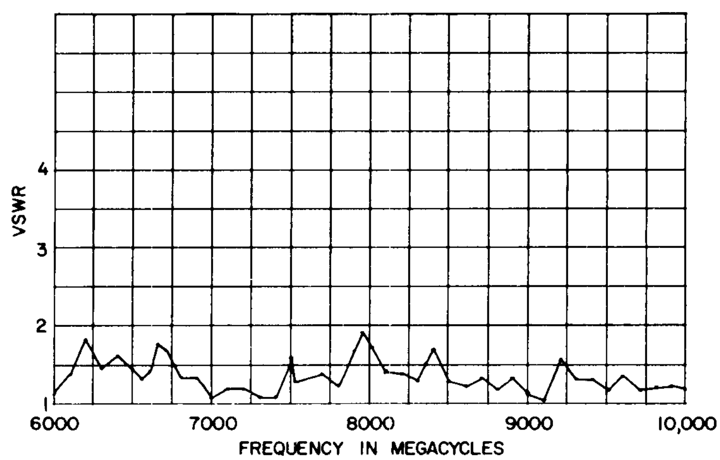


Figure 10. Input VSWR as a Function of Frequency,
2 Ft. Antenna

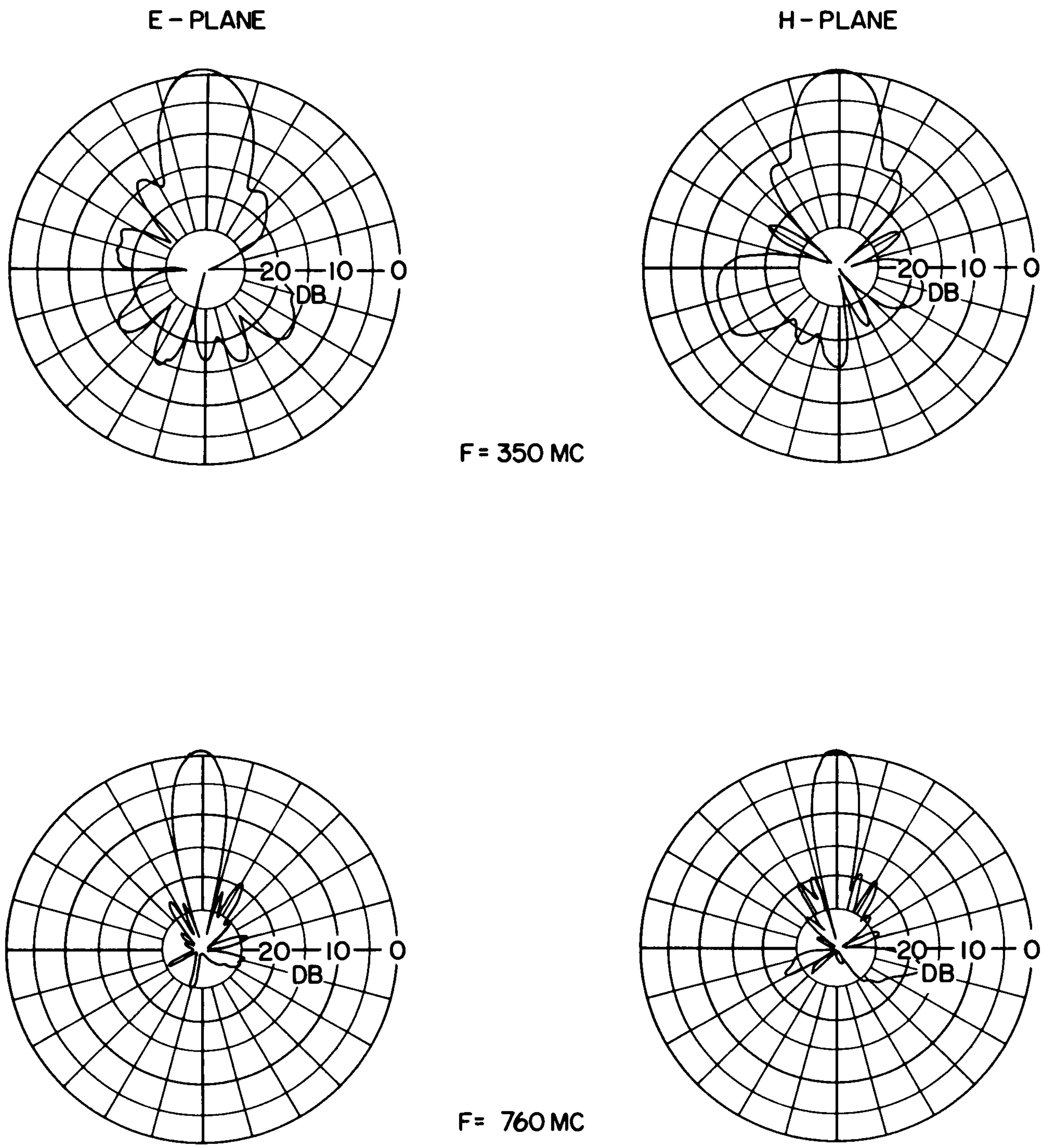


Figure 11. Radiation Patterns of 6-1/2 Ft. Antenna,
350 and 760 Mc.

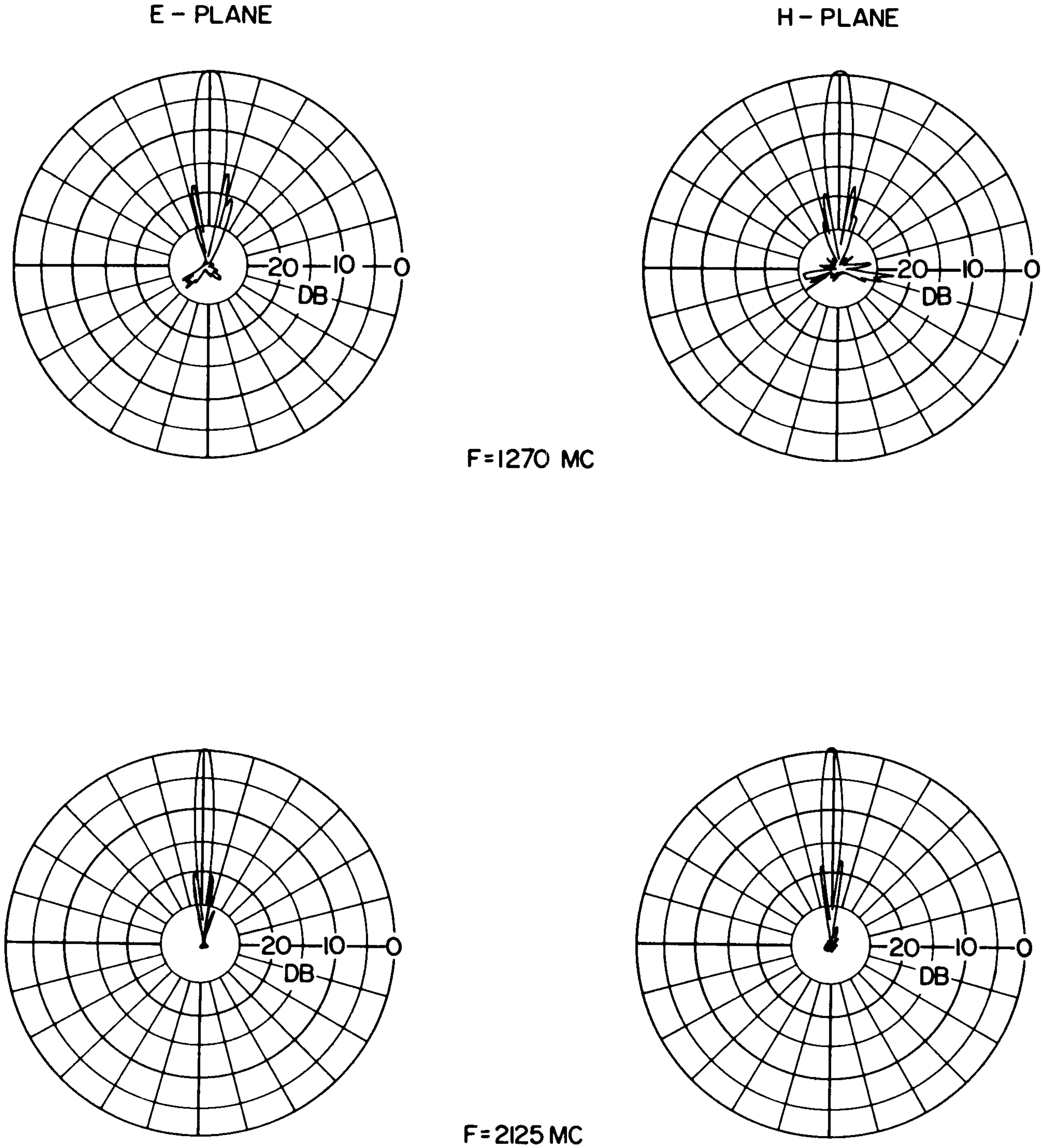


Figure 12. Radiation Patterns of 6-1/2 Ft. Antenna, 1270 and 2125 Mc.

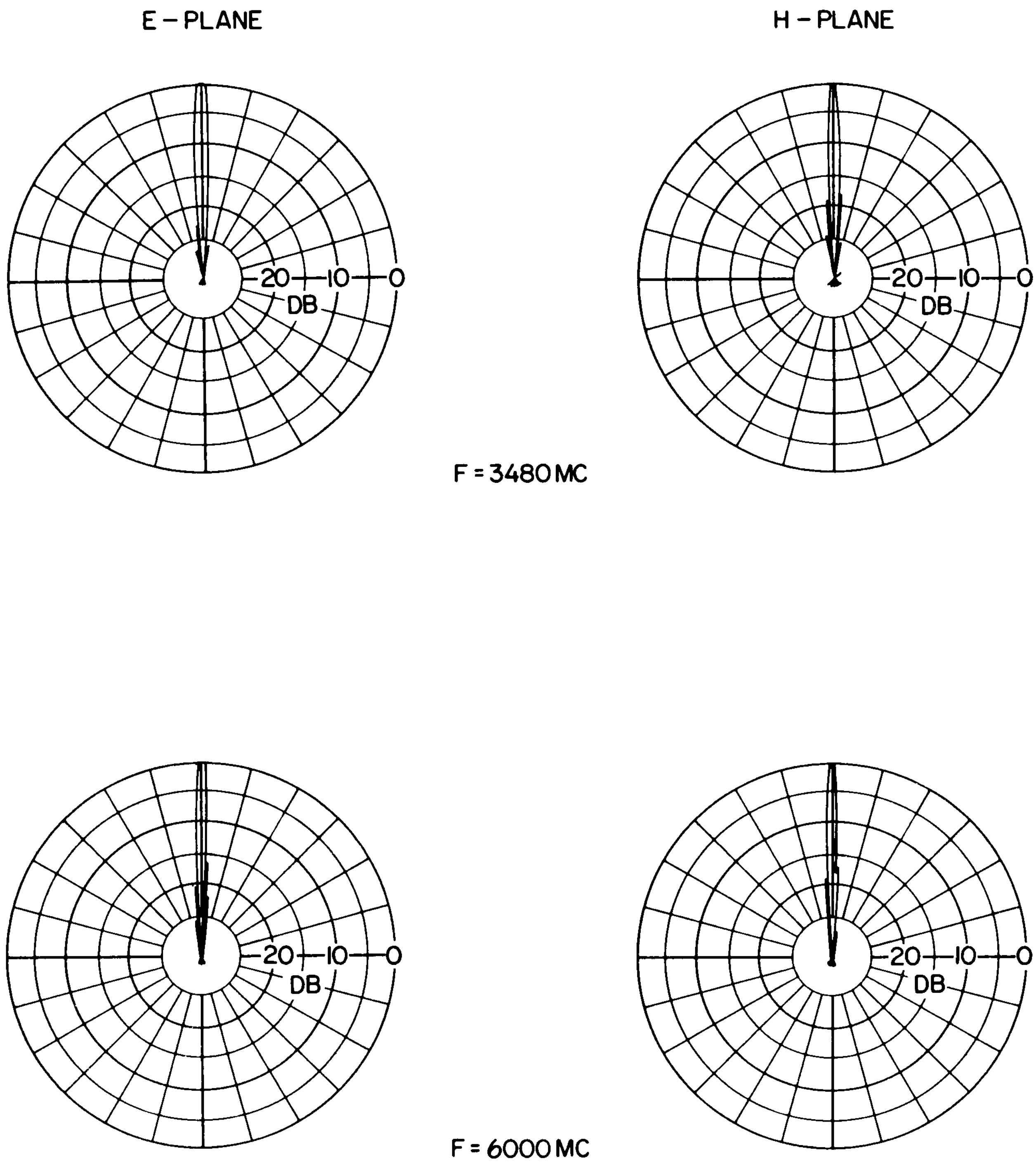


Figure 13. Radiation Patterns of 6-1/2 Ft. Antenna, 3480 and 6000 Mc.

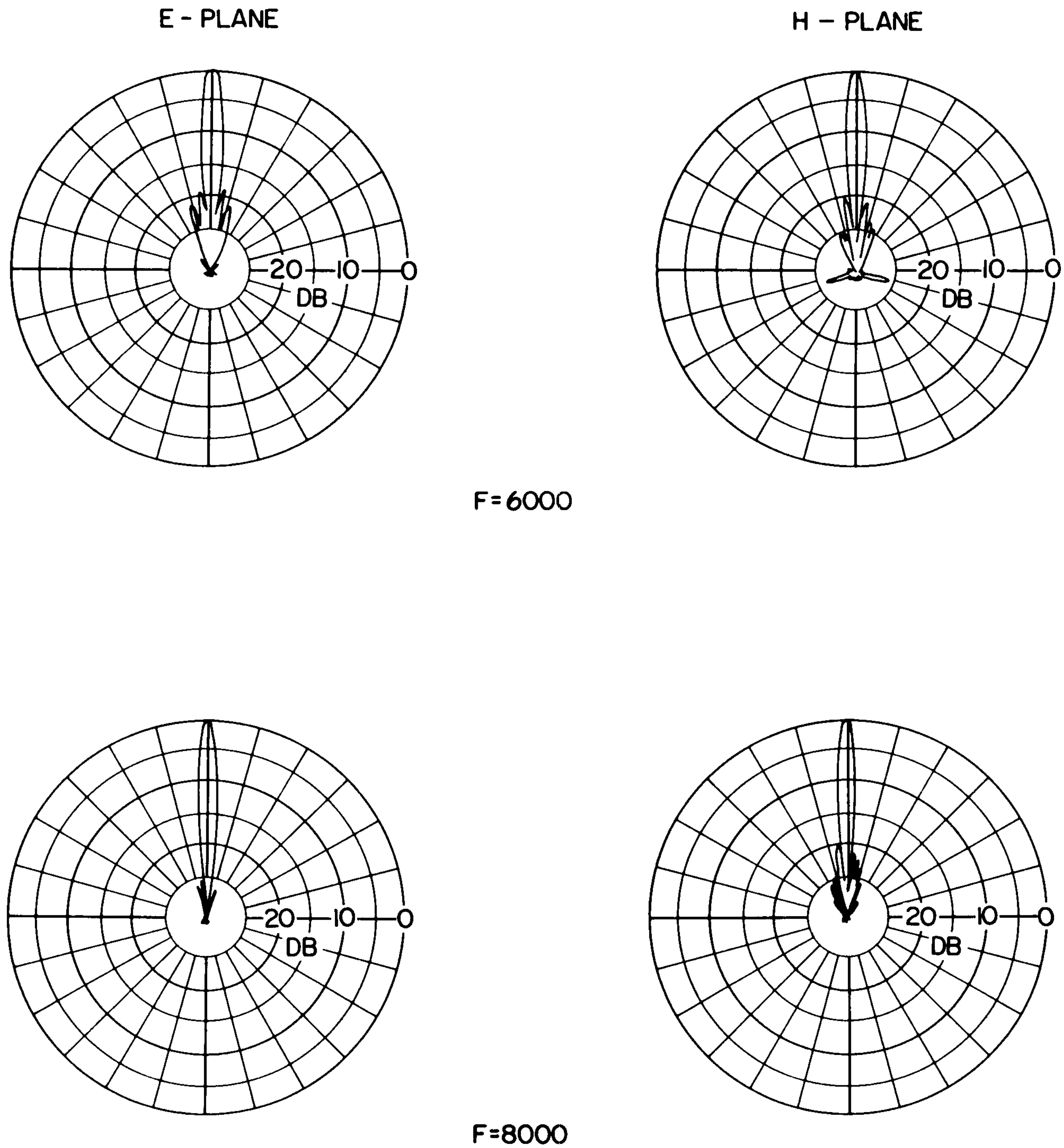


Figure 14. Radiation Patterns of 2 Ft. Antenna,
6000 and 8000 Mc.

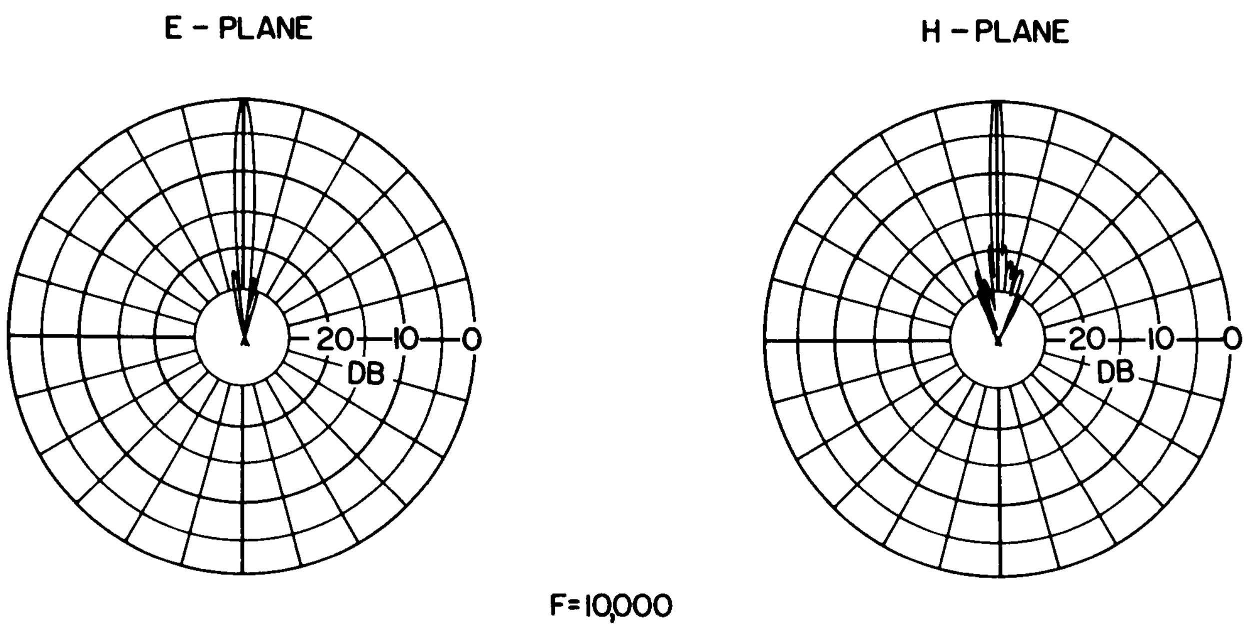
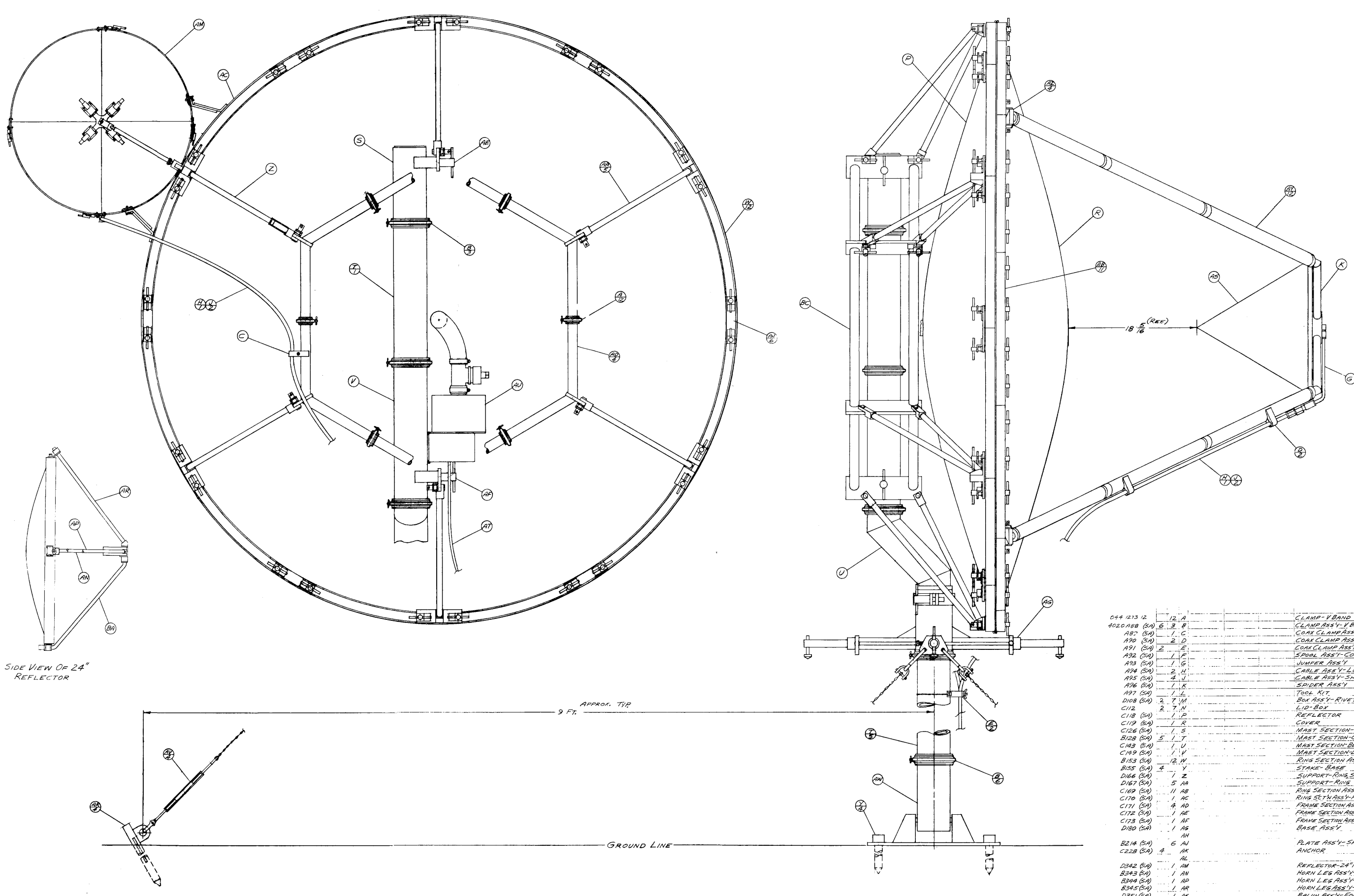


Figure 15. Radiation Patterns of 2 Ft. Antenna, 10,000 Mc.



044 1273 12		12	A	CLAMP-V BAND
4020 A88 (SA)	6	3	B	CLAMP ASS'Y-V BAND
A8? (SA)		1	C	COAX CLAMP ASS'Y-No.3
A90 (SA)		2	D	COAX CLAMP ASS'Y-No.2
A91 (SA)	2		E	COAX CLAMP ASS'Y-No.1
A92 (SA)		1	F	SPOOL ASS'Y-COAX
A93 (SA)		1	G	JUMPER ASS'Y
A94 (SA)		2	H	CABLE ASS'Y-LONG
A95 (SA)		4	J	CABLE ASS'Y-SHORT
A96 (SA)		1	K	SPIDER ASS'Y
A97 (SA)		1	L	TOOL KIT
D108 (SA)	2	7	M	BOX ASS'Y-RIVETED
C112	2	7	N	LID-BOX
C118 (SA)		1	P	REFLECTOR
C119 (SA)		1	R	COVER
C126 (SA)		1	S	MAST SECTION-TOP
B128 (SA)	5	1	T	MAST SECTION-CENTER
C143 (SA)		1	U	MAST SECTION-BOTTOM
C149 (SA)		1	V	MAST SECTION-LOWER
B153 (SA)		12	W	RING SECTION ASS'Y
B155 (SA)	4		Y	STAKE-BASE
D166 (SA)		1	Z	SUPPORT-RING, SPECIAL
D167 (SA)		5	AA	SUPPORT-RING
C169 (SA)		11	AB	RING SECTION ASS'Y-FR.
C170 (SA)		1	AC	RING SCT'N ASS'Y-FR., SPL
C171 (SA)		4	AD	FRAME SECTION ASS'Y-No.1
C172 (SA)		1	AE	FRAME SECTION ASS'Y-No.2
C173 (SA)		1	AF	FRAME SECTION ASS'Y-No.3
D180 (SA)		1	AG	BASE ASS'Y
			AH	
B214 (SA)		6	AJ	PLATE ASS'Y-SPLICE
C228 (SA)	4		AK	ANCHOR
			AL	
D342 (SA)		1	AM	REFLECTOR-24" PARAB.
B343 (SA)		1	AN	HORN LEG ASS'Y-No.2
B344 (SA)		1	AP	HORN LEG ASS'Y-No.3
B345 (SA)		1	AR	HORN LEG ASS'Y-No.4
D351 (SA)		1	AS	BALUN ASS'Y-FOAMED
A354 (SA)		1	AT	CABLE-BLOWER
D357 (SA)		1	AU	BLOWER ASS'Y
A358 (SA)	4		AV	CHAIN-ANCHOR
A359 (SA)	1		AW	TOWER BASE ASS'Y
C364 (SA)		12	AY	LEG-SPIDER SUPPORT
B380 (SA)		4	AZ	FEED LEG BR'K'T ASS'Y
C383 (SA)		1	BA	SMALL HORN ASS'Y
B87 (SA)	1		BB	MAUL-MODIFIED
F400 (SA)	1	X	BC	
044 0011 30	1		BD	CONVERTER-VIBRATOR
A86 (SA)	1		BE	CONVERTER CABLE ASS'Y
B85		2	BF	BOARD-PARTITION

6. BOARD (BF) TO BE PLACED BETWEEN ANY OTHER CONTENTS OF A BOX (M) & REFLECTOR (P) OR COVER (R).
5. AIR PRESSURE IN BALLOON TO BE MAINTAINED AT SEVEN INCHES OF WATER.
4. INNER ROPE CIRCLE OF COVER (R) & REFLECTOR (P) MUST LIE OUTSIDE ALL RING SECTIONS.
3. CONVERTER (BD) & CONVERTOR CABLE (BE) IS FURNISHED FOR INSTALLATIONS WHERE 110 V IS NOT READILY AVAILABLE.
2. MAUL (BB) IS FURNISHED FOR DRIVING ANCHORS (AK).
1. SPOOL ASS'Y IS FURNISHED FOR FORMING CABLES (H) & (J) TO BE PLACED IN BOXES (M).
NOTES:

Figure 16. Assembly Drawing

CER-941

LOG PERIODIC FEEDS
FOR LENS AND REFLECTORS

R.H. DuHamel

F.R. Ore

1 April 1959

This paper presented by the author at the
National IRE Convention March 1959

STAT

A PUBLICATION OF

THE RESEARCH AND DEVELOPMENT LABORATORIES

Department 30

Cedar Rapids, Iowa

STAT

Printed in the United States of America

Sanitized Copy Approved for Release 2011/09/19 : CIA-RDP78-03424A002000080049-0

LOG PERIODIC FEEDS FOR LENS AND REFLECTORS

R. H. DuHamel and F. R. Ore
[redacted]

Abstract

The application of unidirectional log periodic antennas as feeds for lens or reflectors to cover 10:1 or 20:1 bandwidths is described. Information on the primary patterns, phase center variation, input impedance, and aperture blocking of trapezoidal-tooth sheet structures is given so as to allow the design of feeds for a variety of lens and reflectors. Final results of pattern, gain and impedance measurements on a four-foot dish over the frequency range of 600 to 6000 mc are presented and a discussion of the slight sacrifice in gain to achieve this bandwidth is given.

Introduction

There are many applications in the communications, search, and ECM fields where it is quite desirable to have a high-gain antenna which will work over an extremely wide frequency range. Lens or reflector type antennas are often used, but their bandwidths have been limited by the primary feed. Ideally, the radiation pattern and input impedance of the primary radiator should be independent of frequency. The bandwidths of previous primary radiators have usually been on the order of 2 or 3:1. However, the recent discovery of log periodic[1,2,3,4] and angular[5] antennas with essentially frequency-independent operation over bandwidths of 10 or 20:1 provides the basis for new wide-band primary radiators. This paper presents results of an investigation of the problems involved in the application of unidirectional log periodic feeds to reflector-type antennas. Sufficient information on the primary patterns, phase center, input impedance and aperture blocking of sheet trapezoidal-tooth log periodic structures is given to allow the antenna engineer to design feeds for a variety of lens and reflectors. Experimental results are given for a four-foot dish operating over the frequency range of 600 to 6000 mc.

Log Periodic Feed

Figure 1 is a sketch of a sheet trapezoidal-tooth log periodic antenna which will be considered in this paper as a feed. The angles α, β, and ψ define the extremities of the teeth, the tooth support section and the angle between the two half structures, respectively. The design ratio τ is defined as $\frac{R_{N+1}}{R_N}$. The ratio σ is set equal to $\sqrt{\tau}$. Since these antennas have been described previously, only a brief description of them will be given here.

The geometry of this type of structure is chosen so that the electrical properties must repeat periodically with the logarithm of the frequency. If the variation over one period is small, it is therefore small for all periods and the result is an extremely wide-band antenna. A period of frequency is defined by the range from τ f to f. The antenna produces a

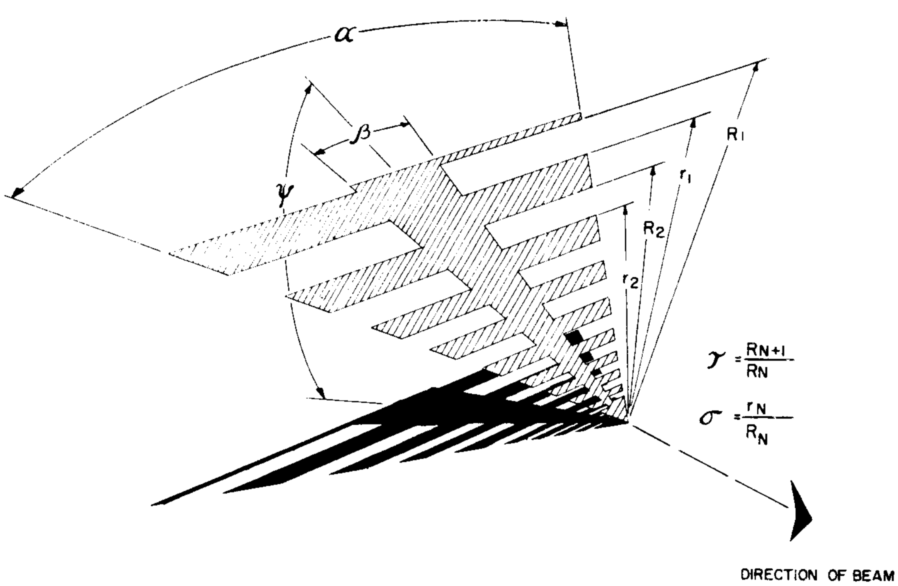


Figure 1. Trapezoidal-Tooth Log Periodic Structure

unidirectional, horizontally polarized beam pointing in the direction which the structure points. The two halves of the antenna are fed against each other either with a balanced line running between the two halves or an unbalanced line running along the center line of one half structure. The low-frequency cutoff occurs approximately when the longest tooth is 1/4 wavelength long and the high-frequency cutoff occurs when the shortest tooth is somewhat less than 1/4 wavelength long. The E- and H-plane patterns are the patterns in the xy and yz planes respectively. It is relatively easy to design these antennas to operate over 10:1 or greater bandwidths with essentially frequency-independent radiation patterns and input impedance.

General Feed Requirements

Obviously, for a very wide frequency range, the electrical characteristics of the feed should be essentially independent of frequency. The important electrical characteristics are the feed radiation pattern, input impedance, phase center, and the aperture blocking. The radiation patterns should be unidirectional and should have E-plane and H-plane beamwidths which give optimum gain for a given dish. These beamwidths will depend upon the shape of the dish, the F/D ratio and the desired illumination taper.

The requirements on the input impedance would depend upon the application, but in general, it may be said that the vswr should be at least less than 3:1. Of course, for radar applications, the vswr should be much less than this.

It is desirable that the feed look like a point source. Some feeds do not exhibit this property since the phase of the radiation pattern exhibits a complex behavior with radiation angle. The term point source cone is used to define the cone of radiation over which the feed behaves as a point source. In the text, the term "phase center" will also be used to refer to the equivalent point source. It is desirable that the E-plane and H-plane phase centers coincide.

Aperture blocking due to the feed can lead to increased secondary pattern side lobes and beamwidths. For extreme bandwidth applications using log periodic feeds, this can become a serious problem since the feed is many times the required size at the high end of the frequency range.

The ability of log periodic feeds to satisfy these feed requirements will be discussed in the following paragraphs.

Pattern Characteristics

Figure 2 is a curve of the angle, δ , subtended by a parabolic reflector as a function of the F/D ratio. In order to obtain high gain and low side lobes with a dish antenna, it is desirable to taper the aperture illumination. The optimum amount of taper[6] is a rather insensitive function of the F/D ratio with an average value of about 9 to 10 db. Thus, for most cases, figure 2 can be used directly to determine the desired 10-db beamwidth of a feed for a given F/D ratio.

Sample voltage patterns of a trapezoidal-tooth log periodic antenna are given in figure 3 over a 10:1

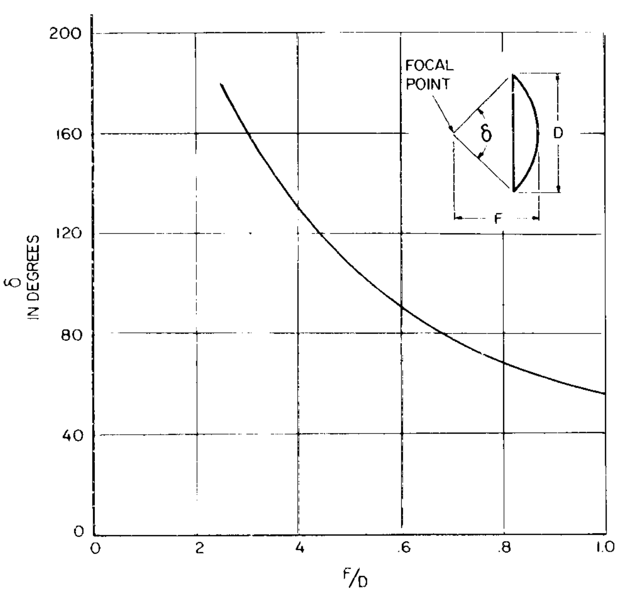


Figure 2. Plot of Angle δ Subtended by a Parabolic Reflector Vs the F/D Ratio

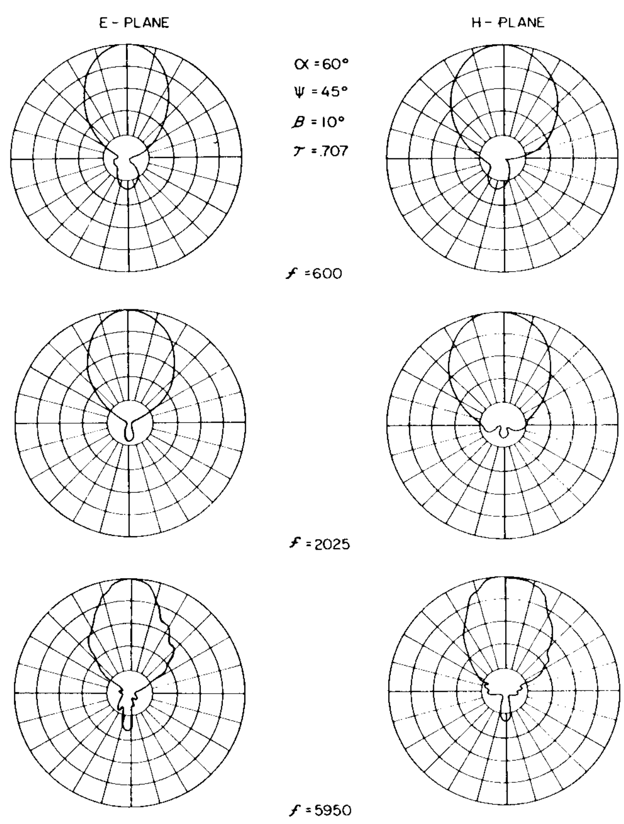


Figure 3. Patterns of a Logarithmically Periodic Feed Over a 10:1 Frequency Range

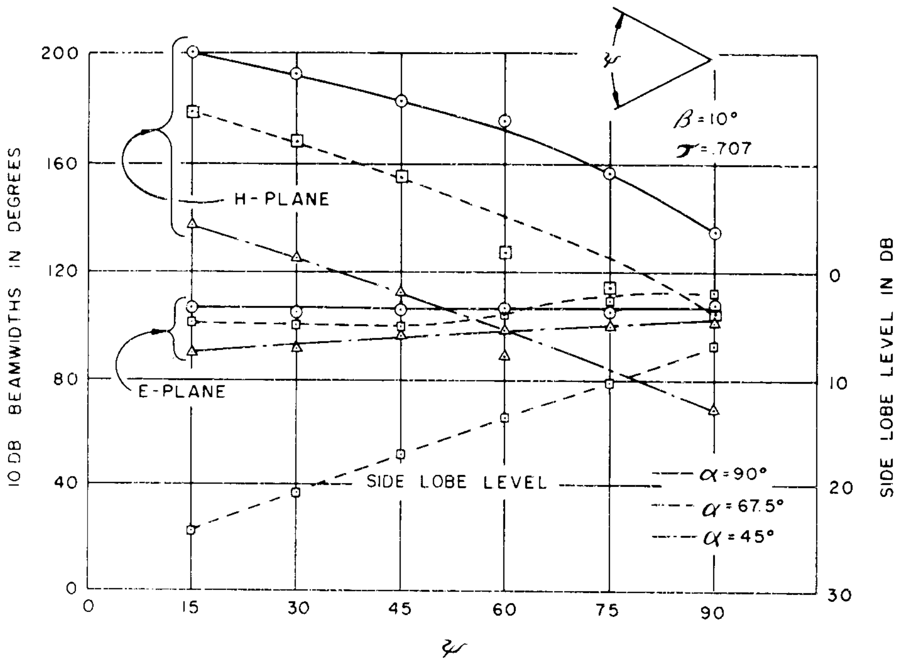


Figure 4. E-and H-Plane 10-Db Beamwidths and Side-Lobe Level as a Function of ψ

frequency range. These demonstrate the small variation of the beamwidths over the frequency range. The variation of the beamwidths is generally on the order of ± 8%.

The beamwidth and side-lobe level can be controlled to a considerable extent by the design parameters α, β, ψ and τ. Figure 4 shows the variation of the E- and H-plane beamwidths and side-lobe level as a function of ψ for several values of α. For these curves, β and τ are held fixed at 10° and 0.707, respectively. It will be noticed that the H-plane beamwidth decreases rapidly with increasing ψ and decreasing α. The side-lobe level, shown only for α = 67.5°, increases with increasing ψ. Figure 5 shows the vaiation of the E- and H-plane beamwidths as a function of α with ψ held fixed.

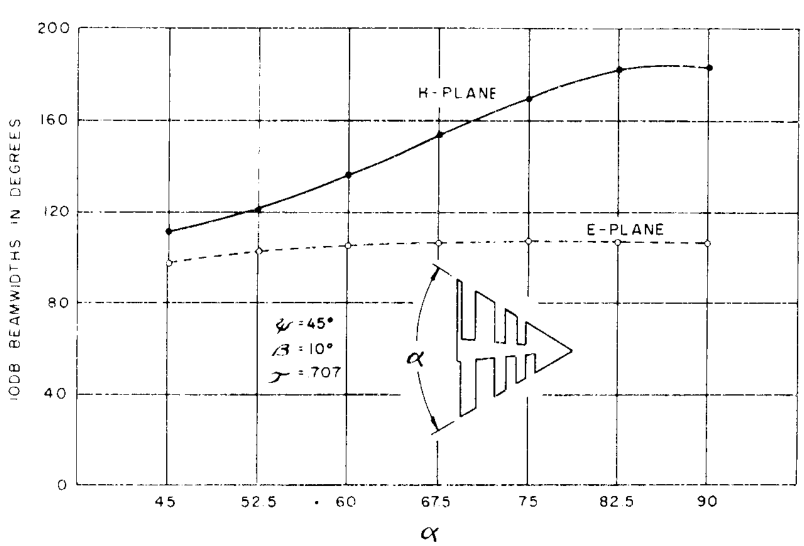


Figure 5. E-and H-Plane 10-db Beamwidths as a Function of α

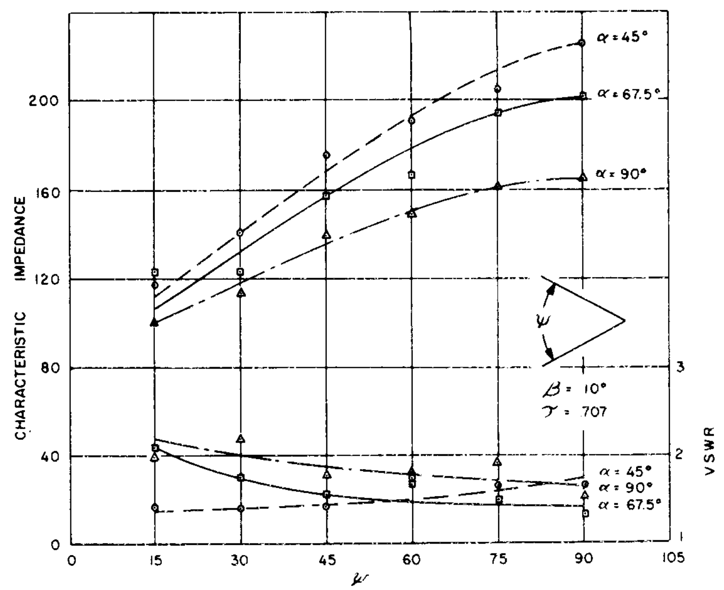


Figure 6. Characteristic Impedance as a Function of ψ

It will be noticed from these figures that the H-plane 10-db beamwidth can be easily controlled over the range of 70° to 200° by the parameters α and ψ. However, it is evident that the E-plane beamwidth is quite insensitive to these parameters since the variation is only from 90° to 110°. Although it has not been investigated thoroughly, some additional control of the E-plane beamwidth can be obtained with the parameters β and τ.

Because of their frequency independence, the pattern characteristics of this log periodic feed are ideally suited for feed applications with H-plane F/D ratios of 0.2 to 0.8 and E-plane F/D ratios of 0.45 to 0.65. For larger F/D ratios a multielement array of log periodic structures may be used.

Impedance Characteristics

If the input impedance of a log periodic antenna is plotted on a Smith Chart over a frequency range of several periods, it will be found that the locus forms a circle with the center lying on the zero reactance line. The characteristic impedance of the antenna is defined as the geometric mean of the maximum and minimum real values on the locus. The vswr referred to this characteristic impedance is then simply equal to the ratio of the maximum impedance to the characteristic impedance.

The variation of the characteristic impedance and vswr with the angles α and ψ is illustrated in figure 6. It will be noticed that the characteristic impedance decreases as ψ is decreased and α is increased. Except for very small values of ψ the vswr is less than 2:1. For the ψ values of most interest, the characteristic impedance ranges from approximately 100 to 200 ohms. Thus, it is necessary to use a wide-band technique to match this impedance to a coaxial or a balanced line. The tapered line transformers [7, 8] are ideally suited for matching this impedance over theoretically unlimited bandwidths.

When a matched feed is placed in front of a dish, part of the radiated energy will be reflected from the dish back into the feed. The magnitude of the reflection coefficient due to the dish reflection is given by $\frac{g\lambda}{4\pi F}$ where g is the feed gain along the axis of the dish. For a feed with optimum patterns for a dish with F/D = 0.5, this formula implies that D/λ should be greater than four in order to keep the reflection coefficient less than 1/3 (vswr less than two). Although this mismatch can be compensated for narrow band applications, no wide-band compensation methods are available. Thus, it is usually necessary to live with this additional mismatch for wide-band applications.

In general, free space vswr's ranging from 1.5 to 2.0 may be expected with a log periodic feed. When placed in front of a dish, the vswr will increase somewhat depending upon the focal length.

Phase Center

In general, the phase centers of a log periodic antenna do not lie at the vertex or feed point. Rather, they lie at a fixed electrical distance from the feed point. This distance, as measured in wavelengths, is approximately independent of frequency. This means that if the frequency is changed, the phase center of the feed will move relative to the feed point.

The effect of displacing the phase center from the focal point along the dish axis is a quadratic phase error in the dish aperture distribution. If Δ represents the displacement of the phase center from the focal point, then the phase difference of the apperture distribution between the center of the dish and the edge of the dish is given approximately by $\frac{\Delta}{\lambda}\left(1 - \cos\frac{\delta}{2}\right)$ where δ is the aperture angle of the dish. The maximum value of this phase difference should be less than approximately $\lambda/8$ which produces a reduction in dish gain[6] of approximately 0.25 db. For F/D = 0.5, this maximum phase difference requires that the maximum displacement of the phase center from the focal point be less than $\lambda/3$. Thus, it is desirable to design the feed such that the phase center lies within $\lambda/3$ of the vertex if extreme bandwidths are to be achieved.

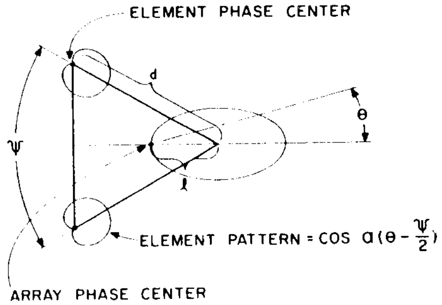


Figure 7. Co-ordinate System for the Derivation of H-Plane Phase Center

The movement of the phase center with the design parameters may be better understood by considering the following simplified theory. Figure 7 is a schematic diagram of the log periodic feed. The two lines separated by the angle ψ represent the center lines of the individual half structures. A basic characteristic of each of the half structures is that they produce a unidirectional pattern which points in the direction of the element, as sketched in the figure. The distance from the vertex of the half structure to the element E- or H-plane phase center is given by d. Both the E- and H-plane array phase centers will lie on the line bisecting the angle ψ and at a distance ℓ from the vertex. In general, neither the E- or H-plane element or array phase centers will coincide, i.e., d and ℓ will have different values for the E and H planes.

Consider first the array H-plane phase center. The H-plane pattern of the array is given by

$$E = e^{j\left(\beta\ell - \beta d \cos\frac{\psi}{2}\right)\cos\theta}\left\{\cos a\left(\theta + \frac{\psi}{2}\right)e^{j\beta d \sin\frac{\psi}{2}\sin\theta} + \cos a\left(\theta - \frac{\psi}{2}\right)e^{-j\beta d \sin\frac{\psi}{2}\sin\theta}\right\} \quad (1)$$

where $\cos a\,(\theta \pm \psi/2)$ represents the element pattern. The constant a is determined by

$$a = \frac{\pi}{2\bar{\theta}} \quad (2)$$

where $\bar{\theta}$ is the half-power element beamwidth. A simple investigation of the phase variation for small angles of θ leads to the following formula for the distance of the array phase center from the antenna vertex.

$$\frac{\ell_H}{\lambda} = \frac{d_H}{\lambda}\left[\cos\frac{\psi}{2} - \frac{\pi}{\bar{\theta}}\sin\frac{\psi}{2}\tan\frac{\pi\psi}{4\bar{\theta}}\right] \quad (3)$$

It will be noticed that the array phase center always lies in front of the line joining the two element phase centers by an amount proportional to the second term of equation (3). It also can be seen that the proper choice of $\bar{\theta}$ and ψ will make the H-plane array phase center coincide with the vertex and that for $\psi = 180°$, the phase center will not lie at the vertex as one might originally expect. This derivation neglects the effect of the presence of one half structure upon the current distribution and radiation pattern of the other half structure. Figure 8 is a comparison of the theoretical and measured values of the H-plane phase center as a function of ψ for three values of α. Notice that fairly good agreement is obtained for $\alpha = 45°$ and 90°, but not for $\alpha = 67.5°$.

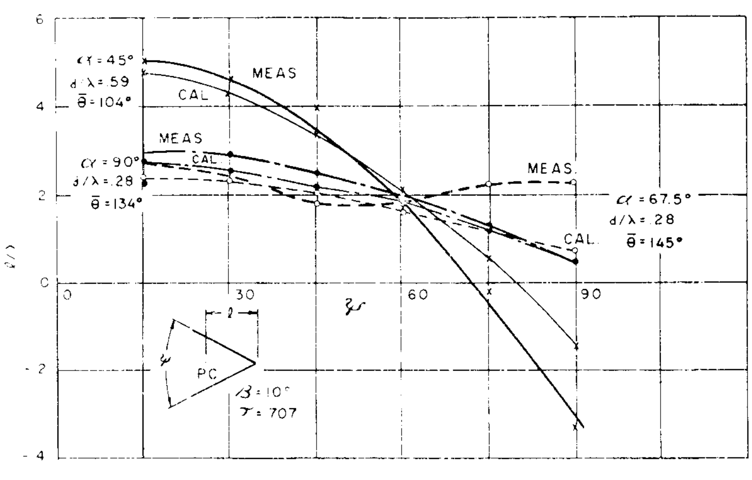


Figure 8. Comparison of Measured and Theoretical H-Plane Phase Center as a Function of ψ

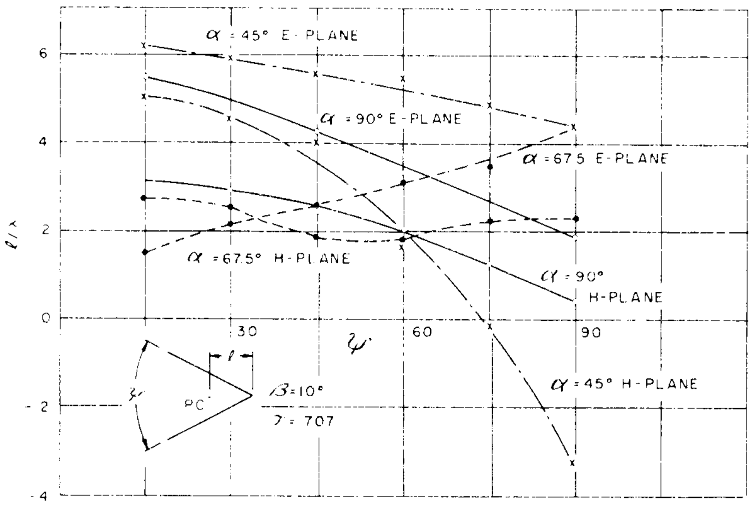


Figure 9. Variation of E and H-Plane Phase Centers with ψ

Consider next the E-plane array phase center. If the element E- and H-plane phase centers coincide, then the array phase center should lie at a point midway between the two element phase centers, which is at a distance from the vertex given by

$$\frac{\ell_E}{\lambda} = \frac{d_E}{\lambda} \cos\frac{\psi}{2} \qquad (4)$$

If the element E- and H-plane phase centers do not coincide, then the array phase center will lie at some other point, which is a complex function of the element pattern and phase centers. Figure 9 shows the variation of both the E- and H-plane phase centers with the angle ψ for the same values of α as shown in figure 8. Again, the phase centers for α = 45° and 90° move as expected, but for α = 67.5° they move in a very peculiar fashion, especially the E-plane phase center.

The variation of the E- and H-plane phase centers with the angle α for ψ fixed at 45° is shown in figure 10. It will be noticed that the E-plane and H-plane phase centers do not coincide and that the results are again peculiar in that the curves do not decrease monotonically as α is increased.

Figure 11 shows the variation of the E-plane phase center with frequency over a half period. Although all of the structures exhibit some variation of phase center (as measured in wavelengths) with frequency, the results for α = 90° are an extreme case. The information given in the previous figures is the average phase center location over a half period.

It is apparent that the phase center characteristics of log periodic antennas are not ideally suited for wide-band feed applications because the E- and H-plane phase centers do not coincide and the phase centers

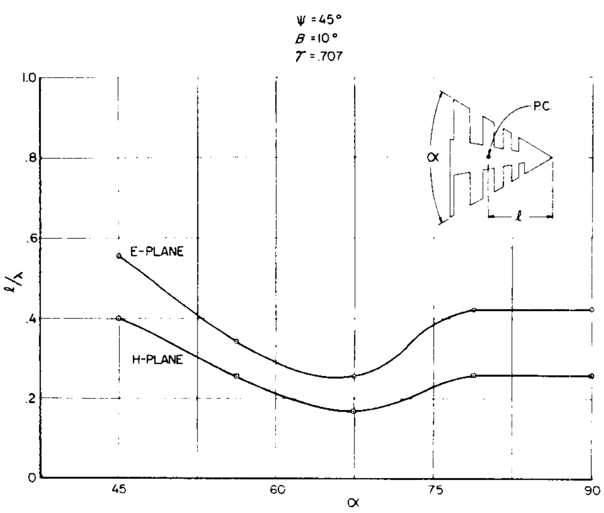


Figure 10. Variation of E and H-Plane Phase Center with α

move with frequency. However, the phase centers are well-defined, and point source cone half angles of 45° are easily achieved. Moreover, the distance of the phase center from the vertex can be made less than $\lambda/2$ which is satisfactory for most applications.

Feed For a Four-Foot Dish

The investigation of log periodic feeds was directed toward the development of a feed for a four-foot dish with F/D = 0.5 to cover the frequency range of 600 to 6000 mc. The final design parameters chosen are α = 60°, β = 10°, ψ = 45°, τ = 0.707. The pattern characteristics of this feed are E- and H-plane average

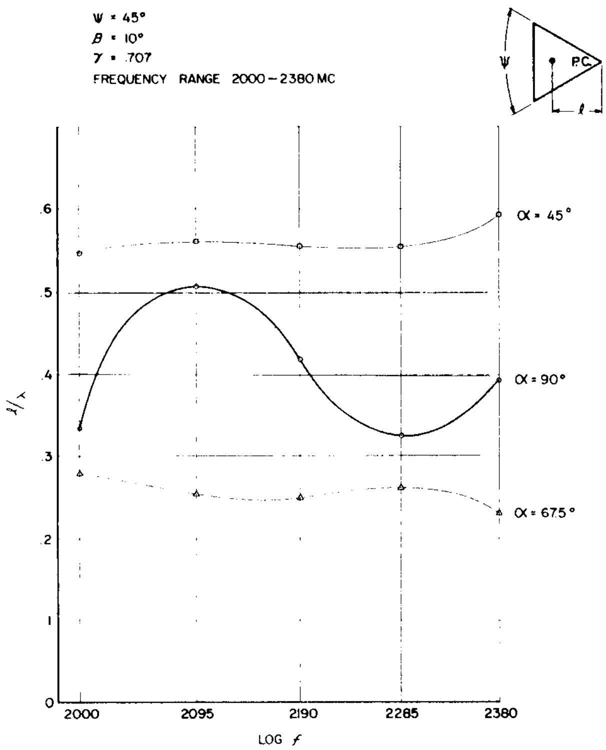


Figure 11. Variation of E-Plane Phase Center with Frequency Over a Half Period of Frequency

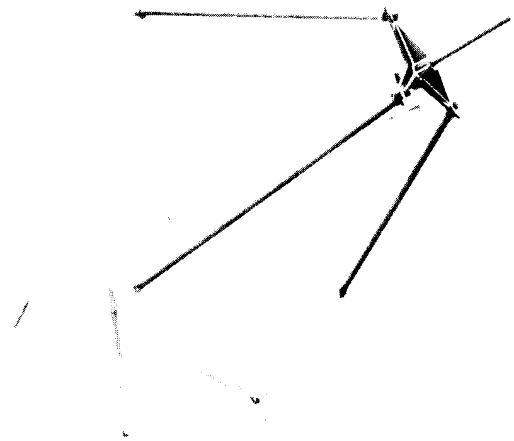


Figure 12. Four-Foot Dish with Log Periodic Feed

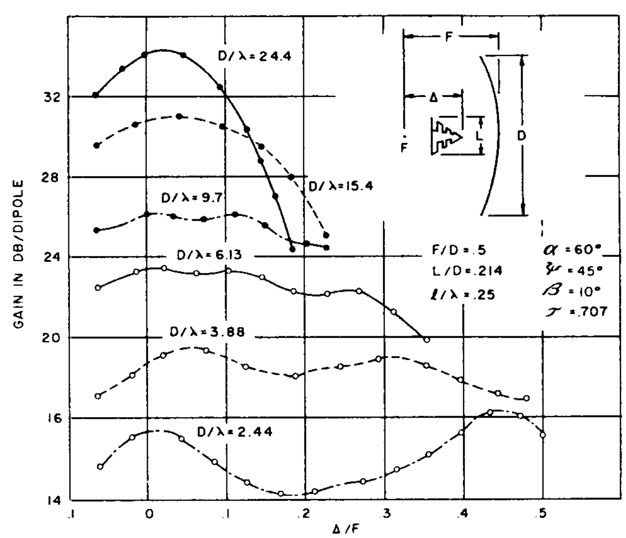


Figure 13. Reflector Gain as a Function of Feed Placement Over a 10:1 Frequency Range

10-db beamwidths of 105° and 135° respectively, and an average side-lobe level in the order of 15 db. The patterns for this feed are shown in figure 3. It should be pointed out that the patterns for 600 and 5950 mc are near the low and high cutoff frequencies for the feed. Patterns over the major part of this frequency range are similar to those for 2025 mc. The distance to the E- and H-plane phase centers from the vertex are approximately 0.3 and 0.2 of a wavelength respectively. The desired 10-db beamwidth for the dish is about 105° (see figure 2). Thus, the H-plane beamwidths of the feed are much larger than desired. When this feed choice was made, it was thought that it would be better to accept less taper in the H plane in order to obtain a phase center as near the vertex as possible. Measurements have indicated that it probably would have been better to use a feed with α =45° and accept the larger phase center variation. Figure 12 is a picture of the four-foot dish with the log periodic feed. The tripod arrangement was constructed so that the location of the feed could be adjusted to determine the effects of phase center variation.

The variation of gain with feed placement is shown in figure 13 for six different frequencies over the frequency range of 600 to 6000 mc. The quantity Δ/F represents the relative displacement of the feed along the dish axis with the positive direction being toward the dish. The point 0 corresponds to placing the feed vertex at the focal point. For the various curves, the diameter of the dish in wavelengths is given. For the lower curves, it is noticed that the gain varies in an approximate sinusoidal fashion due to the effect of the feed back lobe on the dish gain. It will be noticed that if Δ/F is set between 0 and 0.025 that the loss in gain due to variation of phase centers is less than 0.5 db over the complete frequency range. The final results to be given on the patterns and impedance are for the case of $\Delta/F = 0.025$.

Secondary Pattern Characteristics

Logarithmic plots of the secondary pattern for the four-foot dish are given in figure 14. Each radial division equals 5 db. At the lowest frequency, where the diameter of the dish is only 2.44 wavelengths, the

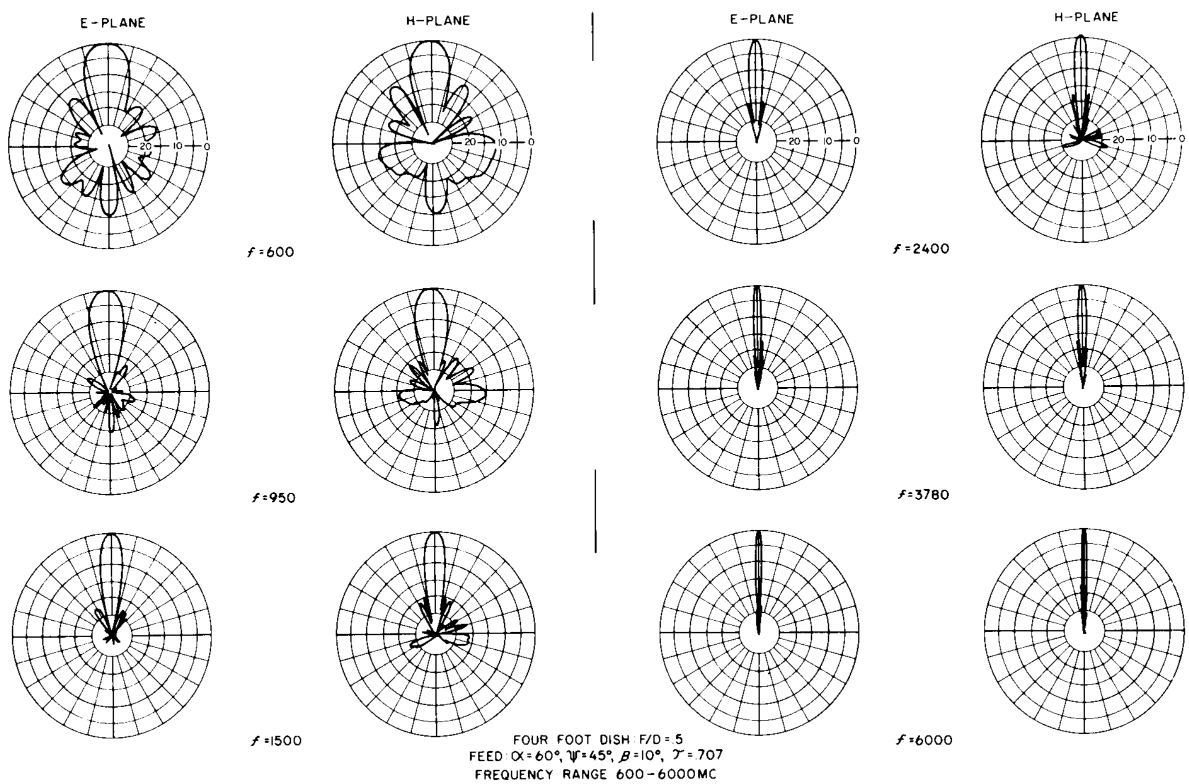


Figure 14. Patterns over a 10:1 Frequency Range

side lobes and back radiation are quite high, as would be expected. Figure 15 summarizes the gain, beamwidths, and side-lobe level for this dish. The product of the dish diameter in wavelengths times the half-power beamwidths in radians has an average value of about 1.15 for the E plane and 1.09 for the H plane. This may be compared to the case for uniform circular aperture illumination for which this product is theoretically 1.02. The gain factor for the dish is on the order of 0.75.

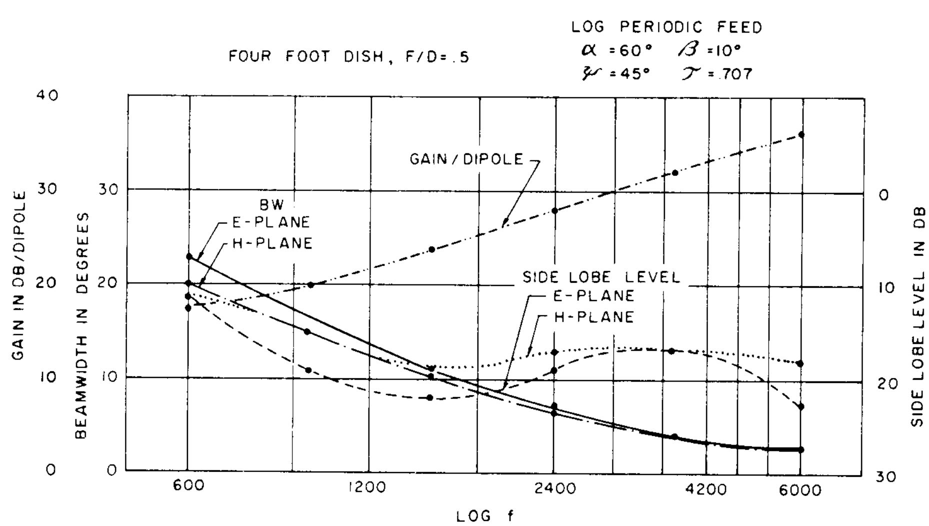


Figure 15. Gain/Dipole, Beamwidths and Side Lobe Level as A Function of Log f over a 10:1 Frequency Range

It will be noticed that the H-plane side-lobe level is higher than the E-plane side-lobe level which is explained by the wider H-plane primary pattern beamwidth. For frequencies about 2000 mc it would be expected that the E-plane side-lobe level should be 20 db or less. Possible causes for this discrepancy are aperture blocking, back radiation from the feed, and phase error in the aperture distribution.

Aperture Blocking

For operation over a 10:1 frequency range, the feed is ten times larger in size than is required at the high end of this range. Attempts were made to measure the total absorption and scattering cross section of the feed over this frequency range. The method used is described in reference 9. It was found that the measurements were quite difficult to perform accurately because of the supporting structure required to hold the feed in position. The measurements indicated roughly that the total scattering and absorption cross section was approximately equal to the physical cross section of the feed regardless of the frequency. Since the physical cross section of the feed is approximately 1/25 the area of the dish, the aperture blocking of the feed should not cause more than a 2 or 3 db increase in side-lobe level.

Primary Feed Construction

A close-up view of the sheet trapezoidal-tooth log periodic antenna and the feed cable is shown in figure 16. For an upper frequency limit of 6000 mc, it is quite difficult to bring in a coaxial line of appreciable size along one of the half structures without distorting the radiation patterns and input impedance at the high end of the frequency range. Consequently, the tapered line balun illustrated in figure 17 was used to feed the structure. Briefly, this consists of a coaxial line with the outer conductor gradually opening up in a prescribed theoretical manner and finally tapered to form a balanced line. Baluns of this type have been built to cover frequency ranges of 50:1 with the vswr less than 1.3. The impedance at the balanced end of this tapered line balun was adjusted to be 150 ohms for purposes of matching the antenna over a wide frequency range. Figure 18 shows the vswr at the input of a tapered line balun for the feed in free space and in front of the dish. The vswr is less than 2:1 over a large portion of the 10:1 frequency range and rises to 3:1 at only two points over this range. The high vswr in the frequency range near 800 mc is due to the reflections from the dish. At this frequency, the dish diameter is less than four wavelengths, which does not satisfy the condition established in a previous section. The vswr could possibly be improved considerably at the high end of this frequency range by taking more care in the design of the tapered line balun and front end of the feed.

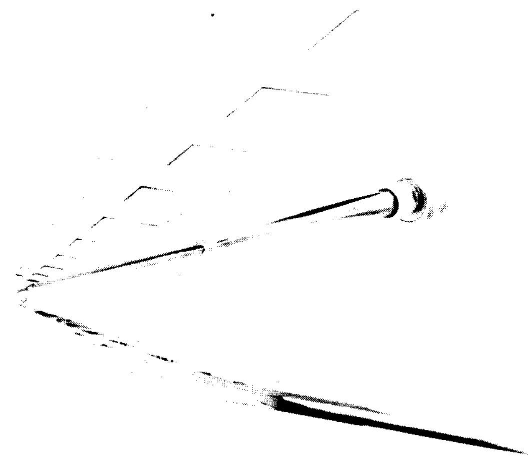


Figure 16. Log Periodic Feed with Tapered Line Balun

Figure 17. Tapered Line Balun

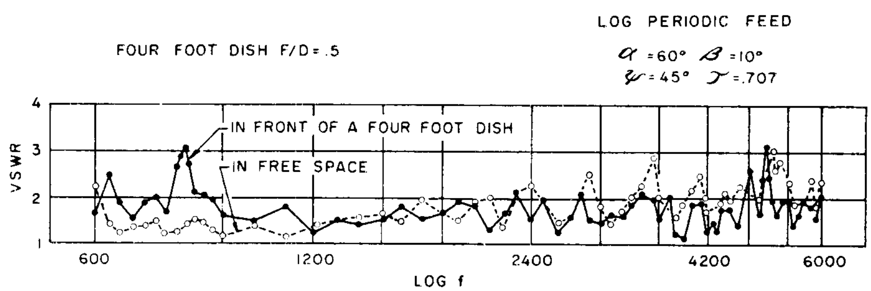


Figure 18. VSWR as a Function of Frequency Over a 10:1 Bandwidth

Conclusions

Log periodic antennas are well suited as extreme bandwidth feeds for reflectors and lens. The impedance characteristics are satisfactory for applications which do not require vswr's less than 2:1. The movement of the phase center with frequency produces only a small degradation of the gain and side-lobe level. Independent control of the E- and H-plane beamwidths allows the design of feeds for a variety of reflector and lens shapes. The H-plane beamwidth for a feed consisting of two half structures may be varied over a wide range by changing the parameters α and ψ. Although the E-plane beamwidth is insensitive to these parameters, it may be decreased easily for large F/D ratios by using a multielement array.

Acknowledgement

It is a pleasure to acknowledge the assistance of Forrest G. Arnold in constructing and testing the antenna models.

Bibliography

1. R. H. DuHamel and D. E. Isbell, "Broadband Logarithmically Periodic Antenna Structures", 1957 IRE National Convention Record, Part I, pp. 119-128.

2. D. E. Isbell, "Non-Planar Logarithmically Periodic Antenna Structures", University of Illinois, Antenna Laboratory TR #30, February 20, 1958 Contract AF 33(616)-3220.

3. R. H. DuHamel and F. R. Ore, "Logarithmically Periodic Antenna Designs", 1958 IRE Convention Record, Part I, pp. 139-151.

4. R. H. DuHamel and D. G. Berry, "Logarithmically Periodic Antenna Arrays", 1958 IRE Wescon Convention Record, Part I, pp. 161-174.

5. V. H. Rumsey, "Frequency Independent Antennas", 1957 IRE National Convention Record, Part I, pp. 114-118.

6. S. Silver, "Microwave Antenna Theory and Design", Radiation Laboratory Series #12, McGraw-Hill, 1949.

7. S. B. Cohn, "Optimum Design of Stepped Transmission-Line Transformers", Trans. IRE, V. MTT-3, April 1955, p. 16.

8. R. W. Klopfenstein, "A Transmission Line Taper of Improved Design", Proc. IRE, V. 44, Jan. 1956, p. 31.

9. J. T. Bolljahn & W. S. Lucke, "Some Relationships between Total Scattered Power and the Scattered Field in the Shadow Zone", Trans. IRE, V. AP-4, January, 1956, pp. 69-71.